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Eco-Innovation Tools for the Early Stages: An Industry-Based Investigation of Tool Customisation and Introduction

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Eco-innovation tools for the early stages: an industry-based investigation of tool customisation and introduction

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To Steve

Thanks for all the great times…

…and for teaching me so much about life.

Acknowledgements

On this, my maiden voyage aboard the good ship ‘Academia’, I have travelled the globe in search of a treasure more valuable than gold and more precious than diamonds – a ‘contribution to knowledge.’ My journey has taken me on many fine adventures throughout Europe; west across the Atlantic to the Americas; and east as far as Japan. Eventually I found the treasure I sought, but only thanks to favourable winds and a fine crew:

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To one and all…

Thank you

Abstract

The challenge of transitioning to an environmentally sustainable system of production and consumption is both a major risk and a significant opportunity for companies involved in the design and manufacture of products. One approach that might assist companies in meeting this challenge is ‘eco-innovation’, which aims to deliver new products and processes that provide customer and business value but significantly decrease environmental impacts.

The aim of the research was to understand how eco-innovation tools can be developed and introduced to a company such that they are adopted into the long-term practices of the company and contribute to the development of eco-innovative products. A ‘toolbox for eco-innovation’ was developed by adapting existing innovation tools for the purposes of eco-innovation. The initial toolbox was tested through in-house trials before subsequent trials in industry with a refined suite of tools. One-day workshops were held with six producers of electrical and electronic equipment. Four of these companies went on to participate in more in-depth tool introduction studies in which the tools were customised to the specific needs of the company and its design team. Formal tool feedback sessions and individual interviews with members of the design team were used to asses the effectiveness of the tool customisations. The organisational drivers and barriers for the long-term adoption of eco-innovation tools were also investigated.

The contributions to knowledge of this research are:

- The development of a toolbox for eco-innovation.
- The validation of tool customisation as an approach to improving the introduction of eco-innovation tools.
- The definition of a generic process for tool introduction based on tool customisation which is appropriate for workshop-based design and innovation tools (including eco-innovation tools).
- Insights into the organisational drivers and barriers for the long-term adoption of eco-innovation tools.
- A model for the management of eco-innovation activities.

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Disclaimer:

The company pseudonyms used within this dissertation are fictional. Any resemblance to any real-life company, product or service name is purely coincidental.

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1 Introduction

This research was initiated following discussions with Environ UK Ltd. who, based on some 10 years experience of working with clients to implement 'Environmentally Conscious Design' (ECD) practices, felt that there was a need for innovation tools that could help to progress companies from incremental approaches to reducing the environmental impacts of their products, such as 'Design-for-Environment' (DfE) and 'eco-design', towards a more radical, 'eco-innovation' approach. The research focuses on the development and introduction of tools to support the 'eco-innovative process' and aims to establish what impact tool customisation - based on an understanding of the requirements of the company and the design team - has on the tool introduction activities and the likelihood that the tools will be adopted into the long-term practices of the company. The organisational drivers and barriers for the long-term adoption of eco-innovation tools are also investigated. The ultimate aim being to increase the number of 'eco-innovative products' making it to the market. The 'eco-innovative process' is defined as a process that:

- considers the entire product life cycle;
- tackles problems at a high systems level;
- has a high level of environmental ambition;
- focuses on the activities up to the end of the conceptual design phase.

An eco-innovative product is defined as a product that results in significantly less environmental harm than the use of relevant alternative products. ECD is used as an umbrella term to describe *any* design or innovation activity that aims to improve the environmental performance of a product.

The research is based within the engineering design domain and focuses on the design and innovation activities of companies who produce Electrical and Electronic Equipment. The research methodology is industrially-based and draws on influences from action research and the case-study approach. The research is based on the development of five eco-innovation tools and their subsequent introduction within four case-study companies, this study investigates the use of eco-innovation tool customisation as a strategy to encourage greater application of such tools within industrial practice. The research makes contributions to both the academic knowledge in understanding of eco-innovation tool introduction and adoption as well as the industrial practice of eco-innovation.

This chapter begins by considering some of the core concepts that underpin eco-innovation. It goes on to outline the ecological need and the business case for eco-innovation before introducing the research problem, objectives and contributions. The final section presents the structure of this thesis.

1.1 Background

Eco-innovation is fundamentally a form of innovation. The ideas and concepts that emerge from eco-innovation activities must be translated into real products through engineering design. This section therefore offers some background to eco-innovation by considering the activities of engineering design and innovation as well as the concept of sustainable development.

1.1.1 Engineering design and New Product Development

Engineering design involves applying scientific and engineering knowledge to solve technical problems and develop solutions which satisfy material, technological, cost, legal, environmental and human-related constraints (Pahl and Beitz, 1995). Engineering design research covers topics such as: the process of engineering design; languages, representations, and environments for design; analysis in support of design; design for manufacture; and life-cycle descriptive models, among other topics (Finger and Dixon, 1989a, Finger and Dixon, 1989b).

One of the perennial interests of engineering design research has been the process by which an idea progresses and develops from a concept through to realisation as an artefact that is competitive and produceable. This work has led to models of, what is commonly referred to as, the 'New Product Development' (NPD) process (Hubka, 1989, Pahl and Beitz, 1995, Pugh, 1991, Ulrich and Eppinger, 2004). The aim of research in this area is to improve both the efficiency of the NPD process, and the quality and competitiveness of the resultant product.

The NPD process model proposed by Ulrich and Eppinger (2004) is shown in Figure 1.1. The authors describe six main stages to the process, starting with the planning stage which leads to the development of a brief or 'target specification' document. This is then used as the basis for concept development in which a wide range of possible solutions are generated and evaluated against criteria taken from the target specification. Once a concept has been selected the design progresses, initially at the broad, systems level, and then at increasingly detailed levels. The product is tested to ensure it meets all the relevant constraints and requirements and refinements are made to correct any failings and ensure a smooth transition to the final stage of production ramp-up.

The main interest within this thesis are the activities that occur within the early stages of the NPD process. This is due to the repeated claims that environmental considerations should be addressed with the early stages of the NPD process because it is here that the majority of a product's life cycle environmental impacts are determined (Charter and

Tischner, 2001, Lagerstedt, 2003, Ritzén, 2000, van den Hoed, 1997). This relationship has not been empirically proven (Baumann et al., 2002), but similar claims can be found within the academic literature in relation to product cost (Andreasen and Hein, 1987, Berliner and Brimson, 1988, Gatenby and Foo, 1990).

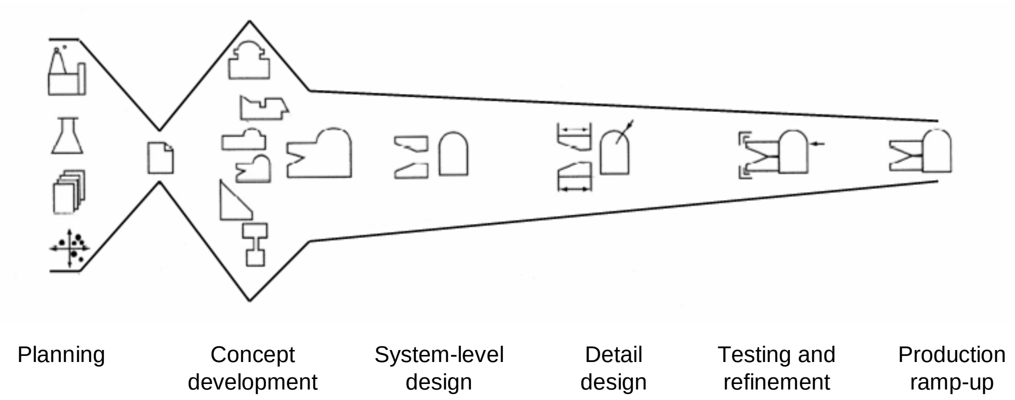

Figure 1.1: The Ulrich and Eppinger model of the NPD process (2004)

1.1.2 Innovation management

The 'Oslo Manual' produced by the OECD (2005) defines innovation as:

> *The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations.*

This definition stresses the point that innovation can occur in many different areas of an organisation, although product innovation is the main focus within this research study. There are significant overlapping areas of interest and inter-relations between product innovation management research and NPD research. Within innovation management research, there has also been significant interest in the *process* of innovation. One of the simplest models of the innovation is the model proposed by Tidd et al. (2005), shown in Figure 1.2.

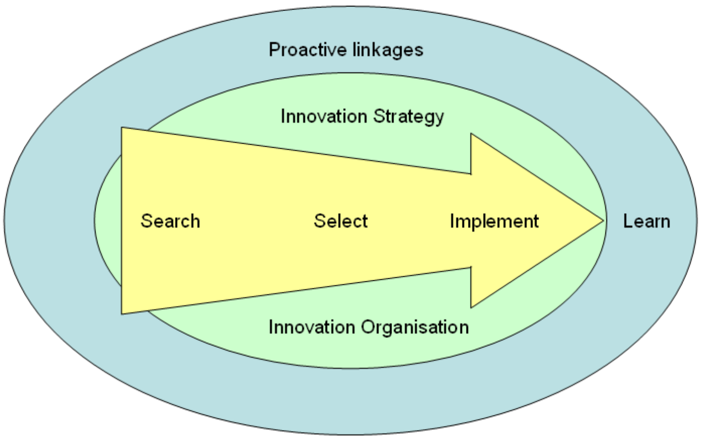

Figure 1.2: The Tidd et al. (2005) model of the innovation process

Within this model there are four main stages of the innovation process: the search for ideas and opportunities; the selection of which ideas to pursue which is informed by the innovation strategy and the organisational context; the implementation of the chosen idea; and finally feedback and learning which is derived from the experiences gained during the process. The NPD process can be considered as a sub-activity of the innovation process, essentially replacing the 'implement' stage within the Tidd et al. model. However, descriptions of the NPD process have occasionally ventured into areas more commonly discussed by innovation management scholars such as innovation strategy and product portfolio planning (Ulrich and Eppinger, 2004). Hence, within the academic literature, the boundaries between the two processes are somewhat blurred.

The eco-innovation tools developed during this research are applicable during the 'search' and 'select' stages of innovation. Hence, in Chapter 2 some of the academic literature related to these stages of innovation is discussed.

1.1.3 Business and sustainability

The global population in February 2010 stands at almost seven billion. Forecasts suggest that it will surpass nine billion by 2050. There are also increasingly high expectations for prosperity and quality of life for this global population. At the same time, there is evidence from many different areas of science that the human activity is having a detrimental impact on the eco-systems of the planet. How can the increasing demands of a growing population be met by the finite resources of planet Earth? This is the contradiction that UN World Commission on Environment and Development attempted to consider in its report 'Our Common Future' (1987). One of the key outputs from this report was a definition of the term 'sustainable development' as follows:

> *'Sustainable development' is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.'*

Since then, efforts to translate this concept into practical business principles have led to the concept of the 'triple bottom line'. The triple bottom line implies widening the scope of measures used to report a company's performance to include ecological and social measures, as well as the normal economic measures (Elkington, 1997). A wide variety of companies now publicly report their performance on ecological and environmental issues either through annual reports (e.g. Philips Corporation, 2009), or through company benchmarking schemes such as Business in the Community (Business in the Community, 2007).

The ultimate aim is not merely to report on, but to make progress towards, sustainable development or 'sustainability'. The term 'Corporate Social Responsibility' (CSR) is the principle that a company must take responsibility for the negative ecological, social, economic impacts its operations have on stakeholders and take action to manage and reduce those impacts. Eco-innovation, by helping to reduce the environmental impacts of a company's products, is one practical way in which a company can make progress in terms of CSR.

1.2 The ecological need for eco-innovation

Over the last forty years in particular, scientists have issued a number of stark warnings that the current patterns of human population growth and consumption are unsustainable and are likely to result in 'overshoot and collapse'. The Club of Rome's 'Limits to Growth' report argued that if the trends of the time were to continue, 'the most probable result will be a sudden and uncontrollable decline in both population and industrial capacity', probably around the middle of the 21st century (Meadows et al., 1972).

More recently scientific debate and media coverage of the specific environmental issue of 'global warming' has increased dramatically. This is based on scientific evidence which shows that atmospheric carbon dioxide (CO2) has increased dramatically since the industrial revolution to 380 parts per million by volume (ppmv) from its previously long term 'stable' levels of between 180-280 ppmv (Stern et al., 2006). Primarily caused by human activity such as the burning of hydrocarbon fuels, it is likely to have serious consequences for humanity and other species (Stern et al., 2006).

It is therefore an imperative that the scientific community and the general public take action to avoid the 'overshoot and collapse' scenario for human kind by considering ways to reduce the environmental impacts associated within human activity.

But what role can manufacturers, engineers and product designers play in meeting these challenges? In fact, it is likely to be a very significant role because the majority of the environmental impacts of human activity are directly or indirectly influenced by a designed product or process of some kind or another. A study by the European Commission of the environmental impacts of products found that 22 product types were responsible for at least 50% of the total environmental impacts of products within the EU-25 countries (European Commission, 2006a). A significant proportion of the 'high-impact' products identified within this report are artefacts developed by engineering designers including domestic heating equipment, electric light bulbs and tubes, household laundry equipment, household refrigerators and freezers, and motor vehicles. The engineering design community, both academics and practitioners, therefore have a significant opportunity - and some would argue a responsibility – to reduce the environmental impacts of products.

This research study focuses on Electrical and Electronic Equipment (EEE) which are an important group of products from an environmental perspective for several reasons. First, these industries continue to grow at a rapid rate. Hence the quantity of products in circulation is increasing rapidly. Secondly, as products such as mobile phones and other gadgets tend to have relatively short useful lives there is an increasing problem with electronic waste. For example, UK citizens are, on average, responsible for 3.3 tonnes of electrical and electronic waste during their lifetimes (Royal Society for Art, 2005). As well as constraints on landfill space, electronics waste is problematic due to the hazardous materials which are often found within electronics products, such heavy metals, endocrine disruptors and persistent compounds, which can leach into water courses resulting in long-term damage to eco-systems as well as the health of flora and fauna. Thirdly, the energy use of electrical and electronic products can be significant, which unless powered by a renewable source of energy, will result in the emission of 'Greenhouse gases'. It is for these reasons that five categories of electrical and electronic products were included within the list of the 22 products with the highest environmental impact in the European Commission study discussed previously.

There are of course other types of products or process which have a higher environmental impact than electrical and electronic products such as automobiles, air transport and freight, and electricity generation. Why not study those? First, the aerospace, electricity generation and, to a lesser extent, the automotive industries have significant financial incentives for improving the energy efficiency of their respective products and processes and hence there is already considerable research activity in these fields. In contrast, energy efficiency and other environmental issues have not historically been a major driver for many types of electrical and electronic products, and hence they have received less attention in terms of their environmental performance. There is therefore significant scope for improvement in the environmental impacts of electrical and electronic products and increasingly strong business case for taking action, as is further described in the following section.

1.3 The business case for eco-innovation

Companies producing EEE must make decisions within the context of highly competitive markets. There therefore needs to be a clear business case for investing in the development of new skills, knowledge, technology and management processes that will be necessary to begin developing eco-innovative products. Whilst the business case for eco-innovation will vary from market to market and from company to company, three of the more common elements of the business case are legislation, competition-driven innovation and corporate social responsibility.

A wide range of environmental legislation now affects EEE producers. For instance, the Waste Electrical and Electronic Equipment (WEEE) Directive (European Commission, 2003b) requires producers that fall within the scope of the Directive to organise and finance the take-back and recycling of their products. The cost of complying with this type of legislation can be significant. In 2006 the UK government estimated the cost to UK companies of complying with the WEEE Directive to be £161-227 million per annum (Department of Trade and Industry, 2006b). This creates an incentive for manufacturers to seek ways to reduce those costs. Applying ECD approaches can help to reduce the cost of complying with legislation and can also identify cost-savings for example through improved resource efficiency, easier assembly or a reduction in the number of components (Kriwet et al., 1995, Smiths Group, 2005).

Some companies are also beginning to see opportunities for innovation when considering the environmental impacts of their products. Within the medical electronics industry there are several companies taking innovative approaches to reduce such impacts. For instance, companies such as Siemens Healthcare and Philips Healthcare have begun to take back large items of diagnostic machinery such as X-ray, angiography and magnetic resonance imaging equipment which they refurbish and then sell into secondary markets (O'Hare et al., 2006). By effectively doubling the useful life of the product with only a relatively small amount of additional energy, materials etc. these companies are significantly reducing the overall impact of these products whilst also gaining significant business benefits such as: access to new lower-cost markets; compliance with the WEEE Directive; and being able to demonstrate environmentally responsible management of their end-of-life products within marketing literature.

Companies such as Lightweight Medical are innovating in terms of their business model. As a small design consultancy, they have chosen to license the intellectual property of their designs for new medical products to manufacturing partners in return for a royalty of the product sales. Their design approach is driven by identifying opportunities for products with improved functional and environmental performance. This has led to the development of award-winning products such as the LINT transport incubator, in which the use of carbon-fibre has made it more than 50% lighter than existing models enabling easier movement and reductions in associated transport emissions (Farish et al., 2005). These types of development are driving environmentally-focused innovation in the medical electronics industry and similar stories can be found in other areas of the electronics industry.

Finally, CSR programmes which aim to ensure that the environmental and social consequences of a company’s actions are clearly understood and managed are increasingly seen as a vital tool in maintaining a company’s brand value. In a recent survey, the share value of companies from across the major industries included in either the Dow Jones Sustainability Index or the Goldman Sachs SUSTAIN list were found to outperform the general market by 10% on average over the period May-November 2008 (Mahler et al., 2009). The authors concluded that even during a widespread economic downturn, companies with effective CSR programmes in place were less susceptible to value erosion. Another benefit of CSR programmes is that they pave the way for additional investment and funding. In 2009 the United Nations Environment Program reported that investors with some 18 trillion US dollars worth of assets had signed up to their Principles of Responsible Investment initiative, including the principle of including environmental and social governance as a key factor in investment decisions (UNEP, 2009).

At the same time, CSR programmes have been found to be one of the main drivers of 'green product development' activities (Jackson and Houlihan, 2008, Argument et al., 1998). Hence, as a key tool for brand value management and attracting investment, the importance of CSR programmes is increasing. This is likely to provide a stronger business case for investment in eco-innovation activities as a means to deliver tangible benefits for CSR programmes.

1.4 Research aim, objectives and contributions

1.4.1 Research aim

From an ecological point of view there is a need for companies to develop products and services with a significant reduction in their environmental impact compared to the existing products. There is also an increasingly compelling business case for developing products with reduced environmental impacts. Despite these drivers, where manufacturers are attempting to reduce the environmental impacts of their products, the types of approach companies take are often incremental in nature, leading to small improvements in environmental performance (Pujari, 2006) rather than the type of step-change reduction in environmental impact that might be delivered by more radical approaches such as eco-innovation (van den Hoed, 1997, Brezet, 1997). There are a number of possible explanations as to why this is. It could be that companies are simply *not interested* in developing eco-innovative products; this seems unlikely given the strong business case outlined previously. Alternatively, it could be that companies are *not able* to develop eco-innovative products. This in itself could be due to a wide variety of reasons such as: a lack of environmental expertise, difficulties in understanding the market need for eco-innovative products, or a lack of appropriate design and innovation tools. This research focuses on the latter issue for the following reasons:

- Based on ten years experience of working with clients to implement ECD practices, the sponsor of this research, Environ UK Ltd., felt that a lack of appropriate innovation tools was one of the main barriers to the successful development of eco-innovative products.
- The academic literature suggests that the availability of appropriate design and innovation tools is an important success factor for the development of products with

reduced environmental impacts (Johansson, 2002, Jones, 2003, Pascual and Boks, 2004, Tukker et al., 2000).

- There are currently relatively few tools that specifically support the early stages of ECD activities (McAloone, 2000, Bhamra et al., 1999), and in particular, eco-innovation activities (Gómez Navarro et al., 2005, Tukker et al., 2000).

These points suggest that there is a need for eco-innovation tools to be developed. However, there is an additional challenge with regard to eco-innovation tools. It has previously been noted that although a good range of support tools exist for other types of ECD activity, the adoption of these tools within industrial practice has generally been poor (Baumann et al., 2002, McAloone et al., 2002, Handfield et al., 2001). There is therefore a risk that any new eco-innovation tools developed would not be adopted into industrial practice. This research attempted to address both of these challenges: developing design and innovation tools that are appropriate for eco-innovation; and ensuring that such tools are adopted into industrial practice. The research aim was therefore formally stated as follows:

> *This research aims to understand how eco-innovation tools can be developed and introduced to a company such that they are adopted into the long-term practices of the company and contribute to the development of eco-innovative products.*

1.4.2 Research objectives

From the research aim presented above, a number of research objectives were formulated. These were:

RO1. To identify the following from the academic literature:

- The main activities in the development of eco-innovative products.
- The types of ECD tools currently available.
- The challenges associated with implementing ECD tools.

RO2. To develop a suitable research methodology and define pertinent research questions.

RO3. To develop and trial a range of benchmarking activities to help understand a company's requirements for eco-innovation tools.

RO4. To gain a better understanding of companies' current responses to drivers for ECD through a preliminary industrial study.

RO5. To identify a number of existing design and innovation tools from the academic literature that have the potential to be adapted for application in an eco-innovation context.

RO6. To adapt said tools for application in an eco-innovation context.

RO7. To assess the suitability of the eco-innovation tools through in-house trials and select the most appropriate tools to form a ‘toolbox for eco-innovation’.

RO8. To gain a better understanding of companies’ needs with respect to eco-innovation tools.

RO9. To introduce the toolbox for eco-innovation to a number of companies who design and produce electrical or electronic equipment through a series of one-day workshops.

RO10. To customise eco-innovation tools based on an understanding of the requirements of a company and its design team.

RO11. To evaluate the success of the tool customisations and the likelihood of eco-innovation tools being adopted into the long-term practices of a company.

RO12. To investigate the drivers and barriers to the adoption of eco-innovation tools.

These research objectives were addressed through a series of research activities which are briefly introduced in Chapter 3 and described in more detail in the relevant sections. Table 1.1 at the end of this chapter summarises how the research objectives were addressed through the research activities and indicates the relevant sections of the dissertation.

1.4.3 Research contributions

The contributions to knowledge of this research are:

- *The development of a toolbox for eco-innovation* – as there are currently relatively few tools that explicitly support eco-innovation activities (Gómez Navarro et al., 2005), the development of more eco-innovation tools will help to ensure that companies looking for a tool to support a particular eco-innovation challenge will find a tool to meet their needs.
- *The validation of tool customisation as an approach to improving the introduction of eco-innovation tools* – tool customisation to the specific needs of a company has previously been suggested as a means of increasing the likelihood of ECD tool adoption. A number of attempts at applying some form of tool customisation strategy have been made previously, but these examples involved limited or no feedback on the effectiveness of this strategy and were based on experiences from single case studies.

This research makes a contribution to knowledge by validating the tool customisation approach based on a formal review of the effectiveness of the tool customisations within four industrial case studies.

- *The definition of a generic process for tool introduction based on tool customisation which is appropriate for workshop-based design and innovation tools (including eco-innovation tools*) – building on the previous work of Ritzén and Lindahl (Ritzén and Lindahl, 2001), the process for tool introduction defined incorporates tool customisation as a strategy for increasing the probability that new design and innovation tools will be adopted into the long-term practices of the company.
- *Insights into the organisational drivers and barriers for the long-term adoption of eco-innovation tools* – during the time spent embedded within the case-study companies, a significant amount of data was collected through workshops, interviews and observations that provided insights into the organisational drivers and barriers for the adoption of eco-innovation tools. This knowledge will be particularly useful to companies attempting to implement eco-innovation tools as they can use the insights to plan appropriate actions to reduce the barriers and enhance the drivers, with the aim of increasing the likelihood of tool adoption.
- *A model for the management of eco-innovation activities* – the model of eco-innovation presented is based on the data collected in industry about where the eco-innovation tools might be best placed in a process and other critical elements needed to manage eco-innovation (such as an eco-innovation strategy). The model addresses a number of the issues raised in the analysis of the drivers and barriers for eco-innovation tools. An important finding was that dedicated eco-innovation should be organised and sit ahead of a conventional NPD process that translates the outcomes of an eco-innovation project into market-ready products.

1.5 Thesis structure

This chapter has provided an introduction to the research including the motivation for the study; some background on the concepts of engineering design, innovation and sustainable development; and the research questions.

In Chapter 2, a comprehensive review of the academic literature is presented covering: eco-innovation; the integration of environmental considerations into design and innovation activities; and the problem of poor uptake of ECD support tools.

Chapter 3 presents the methodology used for the study and includes a description of the philosophical foundations of the approach, a review of potentially relevant methodologies, a summary of the main research activities, and discusses some of the key methodological issues associated with the data collection, processing and analysis methods used.

Chapter 4 discusses the preliminary industrial study and the findings from that study. Chapter 5 describes the development of the toolbox for eco-innovation; the initial, in-house testing of the toolbox; and the selection of five tools taken forward for industrial testing.

Chapter 6 presents the methodology and findings from the one-day workshops and the tool introduction studies. In particular, this chapter introduces the tool introduction process, describes the customisation of the eco-innovation tools and evaluates the success of the customisation activities.

Chapter 7 summarises the findings relating pertaining to the drivers and barriers to the long-term adoption of eco-innovation tools within the case study companies.

Chapter 8 summarises the findings from the various research activities, states the contribution to knowledge of this thesis and outlines areas for future research.

Research objective	Research activity	Chapters/ sections
RO1. - To identify the following from the academic literature: • The main activities in the development of eco-innovative products. • The types of ECD tools currently available. • The challenges associated with implementing ECD tools.	Literature review	2
RO2. - To develop a suitable research methodology and define pertinent research questions.	Development of methodology	3
RO3. - To develop and trial a range of benchmarking activities to help understand a company's requirements for eco-innovation tools.	Development of benchmarking activities	4.1 4.2
RO4 - To gain a better understanding of companies' current responses to drivers for ECD through a preliminary industrial study.	Preliminary industrial study	4.2
RO5 - To identify a number of existing design and innovation tools from the academic literature that have the potential to be adapted for application in an eco-innovation context.	Tool review	5.1
RO6 - To adapt said tools for application in an eco-innovation context.	Initial tool adaptation	5.3
RO7 - To assess the suitability of the eco-innovation tools through in-house trials and select the most appropriate tools to form a 'toolbox for eco-innovation'.	In-house trials	5.4
RO8 – To gain a better understanding of companies' needs with respect to eco-innovation tools.	Benchmarking activities	6.2
RO9 - To introduce the toolbox for eco-innovation to a number of companies who design and produce electrical or electronic equipment through a series of one-day workshops.	One-day workshops	6.3
RO10 – To establish the eco-innovation tool requirements of the design team through a series of tool introduction workshops and feedback interviews.	Tool introduction studies – Week 1	6.4
RO11 - To customise the eco-innovation tools based on an understanding of the requirements of a company and its design team	Tool introduction studies – Week 1	6.5
RO12 - To evaluate the success of the tool customisations and the likelihood of eco-innovation tools being adopted into the long-term practices of a company.	Tool introduction studies – Week 2	6.6
RO13 - To investigate the drivers and barriers to the adoption of eco-innovation tools.	Drivers and barriers interviews	7

Table 1.1: The research questions related to the research activities

2 Literature review

This chapter presents a summary of the academic work related to the task of creating and introducing eco-innovation tools. Section 2.1 begins by reviewing some of the definitions of eco-innovation in order to try and better understand what eco-innovation is. This leads to more operationalised definitions of both the ‘eco-innovative product’ and the eco-innovative process’. Section 2.2 provides an overview of the range of tools currently available to assist companies with Environmentally Conscious Design (ECD) activities, with a particular interest in tools for supporting eco-innovation. Section 2.3 introduces the problem of poor design tool adoption, looking at the explanations for this found within the ECD literature and more generally within the engineering design literature. It goes on to summarise some of the approaches which have been suggested for improving the industrial adoption of ECD tools which might be relevant for eco-innovation. Section 2.4 considers what users’ requirements of eco-innovation tools might include based on previous research into eco-design tools. Section 2.5 discusses the organisational considerations for ECD tool introduction, including a brief introduction to change management theory. Finally, Section 2.6 summarises the main points taken from this review.

2.1 What is eco-innovation?

This section attempts to answer the question, ‘what is eco-innovation?’ by first of all considering some of the academic definitions of eco-innovation. It then goes on to illustrate what eco-innovation is by reviewing some examples of products that demonstrate the principles of eco-innovation. Finally, Section 2.1.3 considers where eco-innovation fits within existing models of New Product Development and innovation

2.1.1 Overview of Environmentally Conscious Design

There have been many different terms used to describe activities which aim to improve the environmental performance of products, with many of the terms being used interchangeably (McAloone, 2000). The terms used within this research are:

- Design for Environment (DfE)
- eco-design
- eco-innovation
- Environmentally Conscious Design (ECD)
- sustainable design

The differences between these terms can be explained by first considering the definition of 'eco-design' provided by the European Commission:

> *Eco-design means the integration of environmental aspects into product design with the aim of improving the environmental performance [of the product] throughout its whole life cycle.* (European Commission, 2005)

The product 'life cycle' mentioned in this definition refers to the various phases that occur during the lifetime of a product including raw materials extraction, production, distribution, use and end-of-life, shown in Figure 2.1. The consideration of the entire life cycle of a product is used here to distinguish eco-design from DfE activities. Hence, DfE is defined within this research as the integration of environmental aspects into product design with the aim of improving the environmental performance of the product with a focus on one phase of the product life cycle e.g. Design for Recycling (Kriwet et al., 1995).

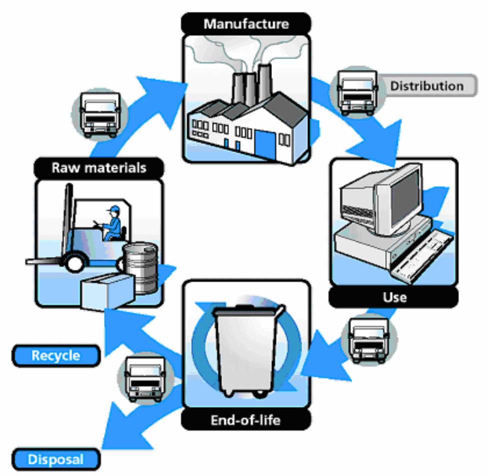

Figure 2.1: The product life cycle

'Eco-innovation' is defined in the following section as an innovation activity that:

- has a high level of environmental ambition;
- considers the entire life cycle of the product;
- develops problem definitions at higher systems levels;
- focuses on the activities up to the end of the conceptual design phase.

Although also used as an interchangeable term for eco-design by some authors (McAloone, 2000), the phrase 'Environmentally Conscious Design' is used within this research as an umbrella term to refer to DfE, eco-design and eco-innovation.

Finally, 'sustainable design' is considered to be any form of ECD that considers social and economic aspects of sustainability as well as the environmental aspects.

In summary, DfE integrates environmental considerations into product design but focuses on one phase of the product life cycle; eco-design broadens this to consider the entire product life cycle; eco-innovation extends eco-design into the early stages of innovation; ECD is an umbrella term for DfE, eco-design and eco-innovation; and sustainable design is any form of ECD that considers social and economic aspects of sustainability as well as the environmental aspects.

2.1.2 How is eco-innovation defined?

The previous section introduced the terms used within this research. This section elaborates the reasoning behind the definition of eco-innovation.

Table 2.1 provides seven examples of definitions of the term ‘eco-innovation’. The first three of these definitions come from academic literature whereas the latter four are from organisations involved in policy formulation. Whilst these definitions may express the general aims of eco-innovation, from an operational point of view, they are rather abstract and say very little about what the activity of eco-innovation looks like in practice. It was therefore decided to develop a more operational definition of eco-innovation for the purposes of the current research.

The first point to make about the definitions within Table 2.1 is that several of them suggest that an eco-innovation can occur in areas such as marketing methods and organisational methods. To help clarify the focus for this research, it is useful to refer to the MEI report which defines four categories of eco-innovation (Arundel and Kemp, 2009):

- *Environmental technologies* – technologies whose primary purpose is the reduction of environmental impacts e.g. waste management equipment, renewable energy technologies.
- *Organisational innovations* – innovations in the way a company manages its environmental impacts e.g. environmental management systems, green supply-chain management.
- *Product and service innovation* – products whose primary purpose is not the reduction of environmental impacts but that do offer environmental benefits compared to relevant alternatives e.g. energy-saving light bulbs, car-sharing schemes.
- *Green system innovations* - alternative systems of production and consumption that are more environmentally benign than existing systems e.g. biological agriculture and renewable-based energy systems.

As research within the engineering design domain, the focus of this research is on ‘product and service innovation’.

The second point to note about the definitions of eco-innovation provided in Table 2.1 is that although they provide details of the output of eco-innovation (i.e. the product or service), they offer relatively little detail concerning the activity of eco-innovation or the

Definition	Source
'Eco-innovation aims to develop new products and processes which provide customer and business value but significantly decrease environmental impact.'	James (1997)
The outcomes of an eco-innovation project should be: '***Appropriate:*** *potential to be integrated in business.* ***Environmentally relevant:*** *potential impact reduction.* ***Radical:*** *step-change from the existing product or service.* ***Original:*** *a new way of fulfilling needs or function* ***System level****: tackles problems at higher levels.'*	Jones (2003)
'Eco-innovation is an innovation that improves environmental performance.'	Carillo-Hermosilla et al. (In pressIn Press)
'Eco-innovation is any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy.'	Competitiveness and Innovation Framework 2007 to 2013 (European Commission, 2006b)
'Eco-innovation is the creation of novel and competitively priced goods, processes, systems, services, and procedures designed to satisfy human needs and provide a better quality of life for all, with a life-cycle minimal use of natural resources (materials including energy, and surface area) per unit output, and a minimal release of toxic substances.'	Europa Innova thematic workshop on 'Lead markets and innovation'. 29-30th June 2006
Eco-innovation is 'innovation' (OECD, 2005) that: • '*results in a reduction of environmental impacts, whether such an effect is intended or not'*; and, • '*is not limited to innovation in products, processes, marketing methods and organisational methods, but also includes innovation in social and institutional structures*.'	OECD (2010)
'Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives.'	MEI report (Arundel and Kemp, 2009)

Table 2.1: Definitions of the term 'eco-innovation'

process that was followed. In light of the aim of the research it was important to establish a better understanding of what the activity of eco-innovation, such that appropriate tools could be developed.

Table 2.2 attempts to glean further insight into the what the activity of eco-innovation involves by separating out the aspects of the definitions that pertain to, or imply, some characteristic of the activity of eco-innovation - the ‘eco-innovative process’ - from those that pertain to the outcome of an eco-innovation project - the ‘eco-innovative product’. The following discussion attempts to elaborate what activities are involved in the eco-innovative process before briefly considering how an eco-innovative product is defined.

Characteristic		**Definition**						
		James	Jones	Carillo-Hermosilla et al.	Europa Innova	OECD	CIP	Arundel and Kemp
Characteristic of eco-innovative product	Has a reduced environmental impact	✓	✓	✓	✓	✓	✓	✓
	Is novel/ original	✓	✓	✓	✓	✓		✓
	Represents value to the customer	✓			✓			
	Represents value to the business	✓	✓					
	Has a wider social benefit				✓	✓		
	Is a radical innovation		✓					
Characteristic of eco-innovative process	Considers the entire product life cycle				✓			✓
	Tackles problems at higher systems levels		✓					
	Has a high environmental ambition	✓	✓		✓		✓	

Table 2.2: Summary of the characteristics of an eco-innovative product and an eco-innovative process according to various definitions

Eco-innovative process

Table 2.2 highlights three possible characteristics of the eco-innovative process; that it should:

- consider the entire product life cycle;

- tackle problems at higher systems levels;
- have a high level of environmental ambition.

Considering the life cycle of the product is considered to be a crucial characteristic for two reasons. First, if only part of the life cycle is considered, more significant problems in other areas of the life cycle may be missed. Secondly, solutions that are effective for one phase of the life cycle may exacerbate or create new environmental impacts in other areas of the life cycle e.g. reducing the amount of material used in manufacture may lead to less durable products that have a shorter lifetime. These conflicts must be considered during the design activity and therefore an eco-innovative process must consider the entire life cycle of the product.

It has previously been suggested that more systemic changes within an industry will lead to greater reductions in environmental impacts (OECD, 2010). This logic is clearly fundamental to Brezet's model of 'eco-design innovation' (Brezet, 1997) which defines four types of ECD activity according to the environmental impact reduction that can be achieved, shown in Figure 2.2. The environmental impact improvement, shown on the vertical axis, is relative to an average product at a set point in time. In this case, the improvement is expressed as an 'improvement factor' where 'factor 2' equates to a 50 % reduction in the overall environmental impact of a product. Brezet describes the four types of ECD activity as corresponding to the stages of development that a company or industry will have to progress through on the way to achieving environmental sustainability. However, they are also clearly linked to systems levels. The first two stages of 'product improvement' and 'redesign product' focus on lower systems levels and deliver small to moderate improvements in environmental performance. The latter stages of 'function innovation' and 'system innovation' focus on higher systems levels and deliver considerably greater improvements in environmental performance.

Unfortunately, there has been relatively little empirical testing of the hypothesis that tackling problems at higher systems levels will lead to greater reductions in environmental impacts (Agopian, 2008). Nonetheless, based on the high face validity of this hypothesis, it is concluded that eco-innovation should aim to tackle problems at higher systems levels.

There has been some debate as to whether or not environmental ambition is a defining characteristic of eco-innovation (Arundel and Kemp, 2009). Carillo-Hermosilla et al (In press) suggest that it is an irrelevant complication as, from society's perspective, it is the reduction in environmental impacts actually achieved that is important, not the ambition. However, in the context of this research, environmental ambition is important because products which deliver reductions in environmental impacts without their ever having been any explicit ambition to do so have achieved this through serendipity. The study of eco-innovation from an engineering design perspective must be based on the assumption that

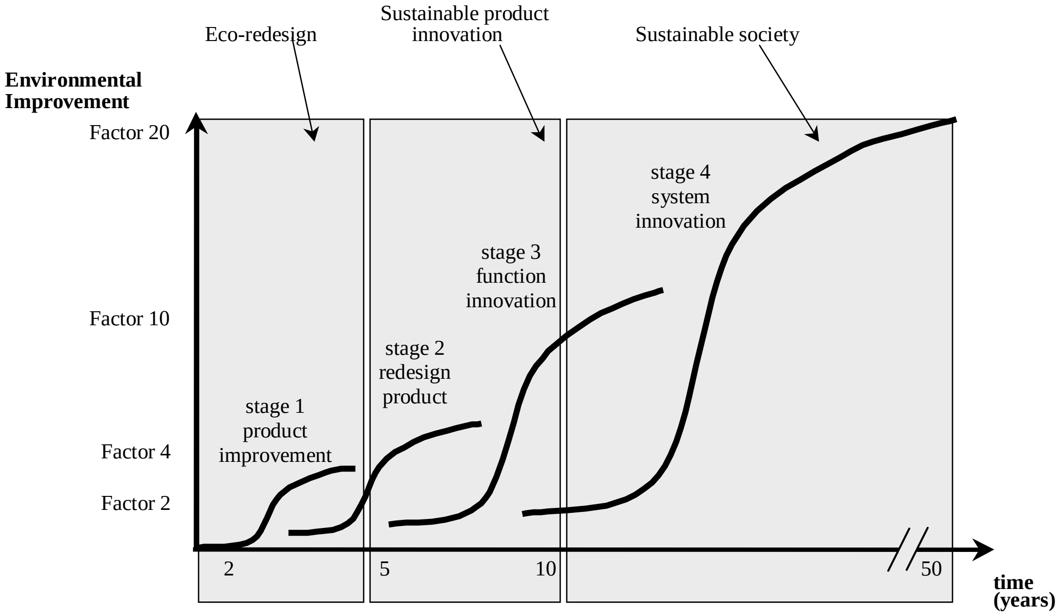

Figure 2.2: Factor X and the four generic levels of eco-design, after Brezet (1997)

reductions in the environmental impacts of a product can be achieved through the systematic application of knowledge and tools, not merely by chance. Hence, for the purposes of this research, a high level of environmental ambition[1] is an important characteristic of the eco-innovative process.

So far it has been suggested that an eco-innovative process should: consider the entire product life cycle; tackle problems at higher systems levels; and have a high level of environmental ambition. Another characteristic that Carillo-Hermosilla et al (In press) suggest that should be considered is the 'product-service' dimension of the eco-innovative process. A 'Product-Service System' (PSS) is "a system of products, services, supporting networks and infrastructures that is designed to: be competitive, satisfy customer needs, and have a lower environmental impact than traditional business models." (Mont, 2002). There is a growing body of knowledge and real-life examples which suggest that the PSS approach can deliver business, customer and environmental benefits (Maussang et al., 2009, McAloone and Tan, 2005). Whilst there area likely to be a number of differences in the specific innovation activities associated with the development of a PSS compared to a conventional product, overall it would appear that the goals of the two approaches are compatible. The PSS approach might therefore be considered as one type of eco-innovative process. However, the product service dimension is not considered to be a key

[1] No formal definition of a 'high level of environmental ambition' is provided as environmental ambition is very hard to measure (Carillo-Hermosilla et al In press) and what constitutes 'high' will be context dependent.

characteristic of the eco-innovative process as eco-innovations that do not involve PSSs are possible.

The final important characteristic of the eco-innovative process that has not yet been discussed is when it should begin, relative to the overall innovation process. It is often stated within ECD literature that incorporating environmental considerations at the earliest possible stage within an innovation project leads to the greatest improvements in environmental performance (Charter and Tischner, 2001, Ritzén, 2000, Jones, 2003, Lagerstedt, 2003, van den Hoed, 1997, Bhamra et al., 1999)[2]. It is suggested that during the early stages of an innovation more degrees of freedom, that is the 'design space', is at its maximum, which allows for more innovative solutions. Figure 2.3 presents an idealised diagram of the NPD process and shows how the design space narrows as the project progresses. Also, as it is claimed that the early stages of NPD activities dictate some 80-90% of a product's environmental and economic costs (Berliner and Brimson, 1988, Bhamra, 2004, Gatenby and Foo, 1990), it seems logical to 'front-load' eco-innovation in the early stages of innovation activities in order to have the greatest chance of making a significant improvement.

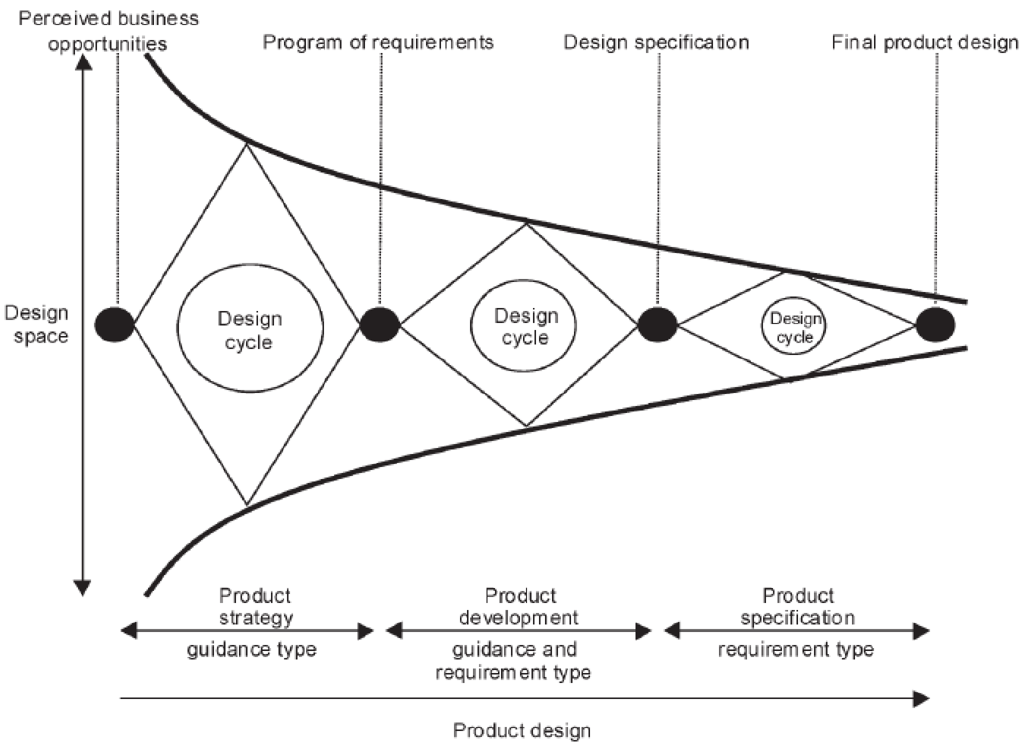

Figure 2.3: An idealised model of the NPD process (Hodgson et al. 1997 cited in Bhamra, 2004)

[2] Although as Bauman (2002) notes, there does not appear to be any empirical evidence to explicitly support this hypothesis.

The ‘early stages’ of innovation will be classified here as the activities up to the end of the conceptual design phase. This point in the NPD process has been chosen as a delimiting feature of the early stages because once a concept has been selected, the design space is fixed to an extent that would make any further substantial improvements in the design of the product from the perspective of environmental performance very difficult. Hence, the end of the conceptual design phase is the logical ‘cut-off point’ for eco-innovation activities. The relationship between the eco-innovation process and models of the innovation and NPD process is discussed further in Section 2.1.3.

In summary, from reviewing the definitions of eco-innovation presented in Table 2.1 and 2.2 as well as wider ECD literature, it is concluded that the eco-innovative process can be described by the following characteristics:

- considers the entire product life cycle;
- tackles problems at higher systems levels;
- has a high level of environmental ambition;
- focuses on the activities up to the end of the conceptual design phase.

Eco-innovative product

Whilst a variety of characteristics of an ‘eco-innovative product’ are presented in Table 2.2, it has previously been suggested that:

> *The relevant criterion for determining whether an innovation is an eco-innovation is that its use is less environmentally harmful than the use of relevant alternatives. (Arundel and Kemp, 2009)*

This view is supported by a number of authors (Carrillo-Hermosilla et al., In press, Foxon et al., 2005). The definition of an eco-innovative product is therefore based on the definitions of eco-innovation provided by Carillo-Hermosilla et al., James and the MEI report and is as follows:

> *An eco-innovative product is one that is significantly less environmentally harmful than the use of relevant alternative products.*

The term ‘significant’ does not provide a precise definition of the level of environmental improvement required to qualify as an eco-innovative product because, in practice, different industries and different companies may have different opinions as to what constitutes a ‘significant’ improvement in environmental performance.

In this section, more operational definitions have been developed for both an ‘eco-innovative product’ and an ‘eco-innovative process’. Section 3.5.1 provides further detail about how these definitions were used within the research activities.

2.1.3 The 'early stages' of NPD and innovation

The working definition of eco-innovation presented in the previous section suggested that eco-innovation should focus on the 'early stages' of NPD and innovation activities. Whilst this is recommended by a variety of authors (Bhamra et al., 1999, Charter and Tischner, 2001, Lagerstedt, 2003, van den Hoed, 1997, Jones, 2003, Olundh, 2006, Ritzén, 2000) there is scarce detail on what is meant by the term 'early stages', or what activities occur within these stages.

To clarify these issues, it is useful to consider some of the models of the NPD process from the engineering design literature. Table 2.3 summarises the key activities completed up to the end of the conceptual design phase according to the NPD process models described by Pahl and Beitz (1995), Ulrich and Eppinger (2004) and BS 7000-2 (British Standards Institute, 2008). Each of these models identifies two distinct phases of activity during these early stages. Whilst each model uses slightly different titles for these phases, they are referred to here as the 'project development' phase and the 'conceptual design' phase. The key point to note from Table 2.3 is that by the end of the conceptual design phase each of the models has led to the development of a requirements specification and the selection of a final product concept. The models show less consistency in describing how projects begin. Within the Pahl and Beitz model the engineering team is presented with 'the task', but there is little explanation of the origins of this task. In contrast, Ulrich and Eppinger's product planning phase, shown in Figure 2.4, details a number of significant activities that occur before the definition of the task, or 'mission statement'. Initially the company must identify opportunities for new products. This could be a request from an existing customer, a new technology that has become available, or the emergence of a new market that the company could feasibly exploit. With some of idea of what opportunities exist, the company must then evaluate those opportunities against their strategic goals in order to prioritise them. Resource is allocated to the projects that have been selected for further development and pre-project planning can begin. Once this is

NPD phase	**NPD model**		
	Pahl & Beitz	*Ulrich & Eppinger*	*BS 7000-2*
Project development	-	Identify opportunities	Project trigger
	Clarify the task	Evaluate and select projects	Develop project proposal
	Formulate the requirements specification	Pre-project planning	Feasibility study
Conceptual design	-	Formulate target requirements specification	Formulate the requirements specification
	Generate alternative concepts	Generate alternative concepts	Generate alternative concepts

	Evaluate the alternative concepts and select the final concept	Evaluate the alternative concepts and select the final concept	Evaluate the alternative concepts and select the final concept
	-	Formulate final requirements specification	-

Table 2.3: Comparison of the key activities of the early stages of NPD process

completed and approved a full NPD project is launched. Each of these areas – identifying opportunities; portfolio planning and resource allocation; and project planning – have received significant attention from innovation management scholars as part of their research into what they term the ‘fuzzy front-end of innovation’ or simply the ‘front-end of innovation’ (FEI) (Koen et al., 2001, Leifer, 1998).

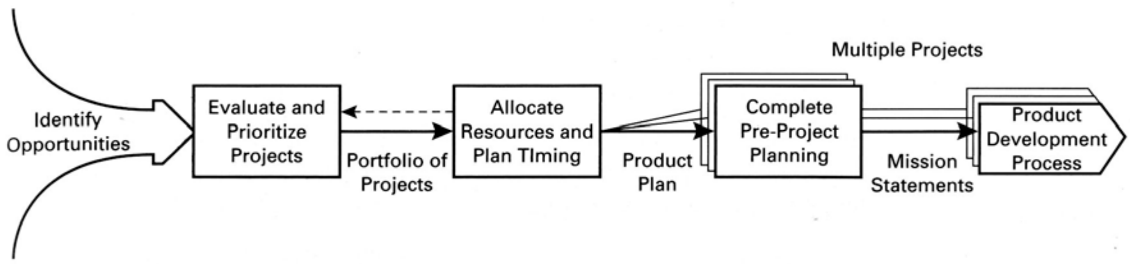

Figure 2.4: The activities within the product planning process of the Ulrich and Eppinger (2004) model of NPD

One notable piece of work that has emerged from the FEI research is the model of the FEI developed by Koen *et al.* (2001), shown in Figure 2.5. This industrially-derived model is useful in that it provides a good summary of the main activities that occur prior to the commencement of an NPD project – something that is rarely discussed in the engineering design literature. The model, developed in conjunction with eight multi-national corporations, involves three elements:

- The inner area which summarises the five main activities involved in the FEI.
- The ‘Engine’ which represents the leadership and culture of the company which drives the FEI activities.
- The ‘influencing factors’ which include the business strategy, the potential supply chain, the state of development of the underlying science for a technology etc.

The authors stress that FEI activities are generally not completed in a linear fashion. Rather, there are a number of activities that need to be completed but they are completed in a very iterative and circular fashion.

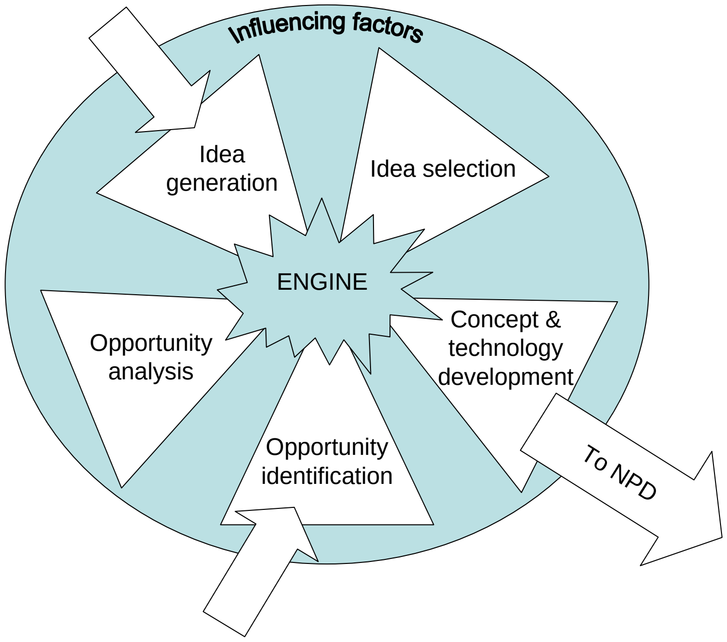

Figure 2.5: A model of the front end of innovation (Koen et al., 2001)

The activities involved in the FEI model are described as follows:

- *Opportunity identification* – this activity is where the company highlights a number of business and technological opportunities that the company may want to pursue. According to Koen et al, the sources and methods employed by the company are the defining aspect of this activity. These can range from formal, systematic tools such as future scenario mapping or problem-solving methods such as the fishbone diagram as well as less formal, ad hoc approaches such as water-cooler conversations or individual insights.

- *Opportunity analysis* – this activity involves gathering together the additional information required in order to make assessments of opportunities. This may involve focus groups to investigate user requirements or initial scientific experimentation to better understand the scientific underpinnings of a new technology. The level of effort put into these activities will be proportional to the size and value of the opportunity as well as the technological or market risk.

- *Idea generation* – as more information about the opportunity emerges the product concept is iteratively developed, and occasionally scrapped in favour of an alternative concept. Concepts may also be generated which are unrelated to any existing opportunity. Such ideas can be fed into the opportunity identification activities, showing that the FEI activities do not proceed in a linear fashion.

- *Idea selection* – normally there are more opportunities and concepts than can be supported with the funding available within the company. The activity of prioritising and selecting appropriate opportunities and concepts therefore becomes crucial to the success of the company. The selection of an idea may be based on a comprehensive portfolio planning approach or can simply be the preference of the CEO. One important comment made by Koen et al. is that it is not uncommon for estimates of economic returns to be wildly inaccurate within FEI activities and so better models for very early-stage cost and revenue estimating are required.

- Concept and technology development – within this activity the formal business case is developed, drawing on the outputs from many of the other activities and hence it is often seen as the final output of the FEI. One thing not acknowledged within the model is that a final decision on whether or not to pursue the opportunity must be made before an NPD project can be launched.

From an eco-innovation perspective, the problem with this model is that it does not explicitly explain how environmental considerations can be integrated into these early stage activities. This problem is discussed further in Section 2.4.2.

In summary, this sub-section has looked at models of the NPD process and the activities involved in the front end of innovation. The scope of the research has been defined in relation to these models as being all activities up to the end of the conceptual design phase.

2.1.4 What examples of eco-innovative products exist?

In this section a number of products which achieve a significant reduction in environmental impacts are presented. Some of the key aspects of the design of these products with respect to the definitions of the eco-innovative process discussed above are highlighted.

Energy-efficient hand dryer

The Dyson ‘Airblade’ hand dryer uses high-efficiency electric pumps to force air through specially designed apertures. These apertures create ‘blades’ of air which ‘cut’ water off the hands of the user as they slowly lift their hands out of the drying chamber, as depicted in Figure 2.6. By blowing the water off the hands rather than trying to evaporate the water

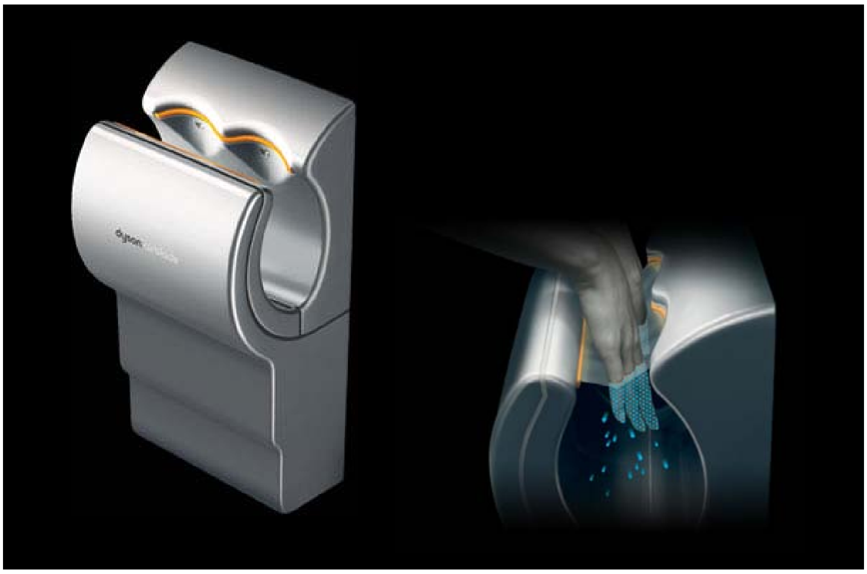

Figure 2.6: The Dyson 'Airblade' hand dryer

off as conventional hand-dryers do, Dyson claims that the Airblade uses 74% less energy and requires 63% less time to dry hands (Dyson Ltd., 2010).

Key points for eco-innovation

- The Airblade demonstrates that products can deliver both functional benefits (less time to dry hands), as well as environmental benefits (reduced energy consumption and carbon emissions).
- This solution focuses on the actual function required ('dry hands'), rather than on improving the function that conventional products offer ('evaporating water off skin').

<u>Water-efficient clothes washing process</u>

Xeros Ltd. have developed a 'virtually waterless' process for washing clothes that uses around 90% less water and 40% less energy than a conventional washing machine (Xeros Ltd., 2009). The process employs reusable nylon polymer beads that absorb dirt. The process still requires the use of a detergent which is mixed with one cup of water per wash. Figure 2.7 shows how this process is being integrated into a washing machine product, still being developed at the time of writing.

The prototype machine is designed for commercial laundry applications although a domestic product is also planned. The machine contains a hopper with 20kg of nylon beads which it is claimed will offer 100 washes. The used nylon beads can be recycled.

Key point for eco-innovation

- The Xeros cleaning process is an example of a new solution principle i.e. rather than trying to reduce the amount of water used, they have developed a solution which uses (almost) no water.

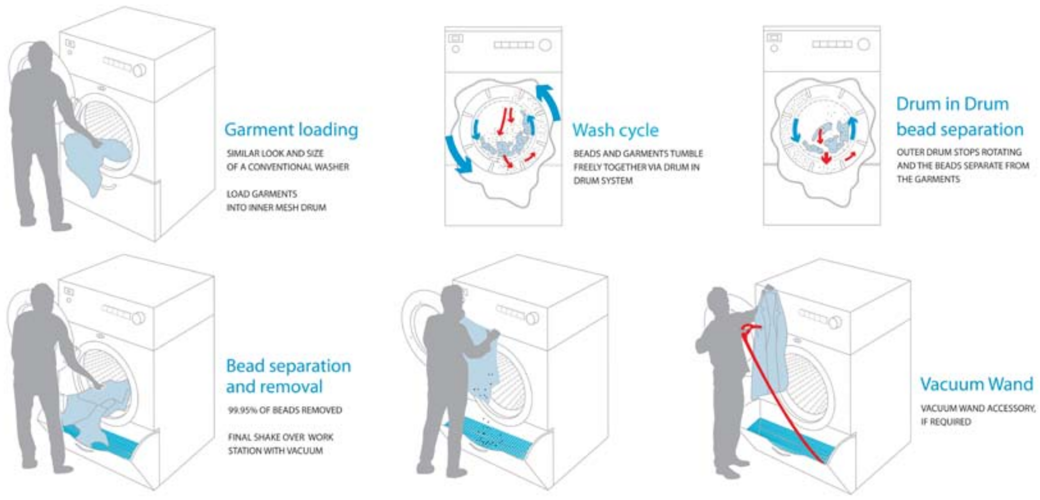

Figure 2.7: The Xeros 'virtually waterless' clothes cleaning process

Energy-saving controller for air conditioning water pumps

Figure 2.8: The 'Econo-pilot' energy-saving controller for air conditioning water pumps (image copyright Yokogawa Electric)

Air conditioning units are energy-intensive products, consuming up to half of the energy used by a building in countries like Japan (Yoshida, 2006). Conventional air conditioning systems vary the flow rate of the refrigerant through the air conditioning units in order to achieve the desired temperature. Energy is wasted because conventional systems are designed to operate at one pressure and so are set to operate at a high pressure, which is only necessary when maximum heating or cooling is required. The 'Econo-pilot', shown in Figure 2.8, intelligently controls the pumping pressure of the system to match the demand. In doing so, it can reduce the annual pump power consumption by as much as 90% (OECD, 2010). The Econo-pilot can be retrofitted and has successfully been installed on a wide variety of buildings including factories, hospitals, hotels and office buildings.

Key point for eco-innovation

- The Econo-pilot is a solution that has been arrived at by tackling the problem at a higher systems level i.e. rather than trying to improve the performance of individual air-conditioning units, the Econo-pilot improves the efficiency of the entire air-conditioning system by intelligently controlling the system pumping pressure.

2.2 Tools for supporting ECD activities

A review of engineering literature by Baumann et al (2002) found some 171 papers that discussed ECD tools (this review is discussed in more detail in Section 2.3.1). Hence there exists a considerable amount of academic literature related to ECD tools. However, for the purposes of this review only a simple overview of the types of tools discussed in this literature is necessary, as is presented in Section 2.2.1. There are considerably fewer tools which are relevant for eco-innovation than for other forms of ECD. Therefore in Section 2.2.2 a more detailed review of some of these tools is presented.

2.2.1 Overview of tool for supporting ECD activities

Figure 2.9 presents an overview of the types of ECD tools available according to the NPD process phase and the type of ECD activity being conducted. From this figure it would seem that there are examples of tools for each of the main ECD activities across all stages of the NPD process. However, Figure 2.9 does not provide any indication of the number of tools available in each area, or how mature or sophisticated those tools are. For instance, a variety of tools for measuring environmental impacts exist that range from quick, but low-accuracy qualitative methods such as the MET Matrix (Brezet and van Hemel, 1997b) up to the highly-accurate, standardised approach of ‘Life Cycle Assessment’ (LCA). The ‘gold standard’ for environmental impact assessment is a full LCA that considers all the materials and energy inputs and outputs at each stage of the product life cycle, from materials extraction through to its final disposal. The results of an LCA can be presented as individual measures for a range of environmental impacts, or as one aggregated score. The approach of LCA has now reached an advanced level of maturity, as confirmed by the establishment of an ISO standard for the process of completing a life cycle assessment (ISO ref). Furthermore, in a survey of 99 Swedish (ref) companies producing various different products, some 28% of the companies claimed to use some form of LCA tool within their NPD activities, which was more than claimed to use FMEAs (26%), design reviews (13%) or even requirement specifications (9%). One major issue with LCA tools is that they can be difficult and time-intensive to use due to the problems in defining the scope and boundaries of an assessment, and the challenges of obtaining accurate data.

Unfortunately, other types of ECD activity do not have the same type of mature and sophisticated tools available. McAloone (2000) has noted that there is a lack of tools to support the early activities of eco-design in general. Gómez-Navarro et al (2005) have conducted a large review of ECD tools described in academic literature covering some 65 unique tools. The tools were categorised according to the ECD problem level that they were relevant to: adaptation, re-design, eco-design or eco-innovation. They concluded that there were very few examples of eco-innovation tool – just nine tools in total compared to 34 for eco-design. The eco-innovation tools were predominantly focused on idea generation and project planning activities and were tailored towards the 'use and maintenance' phase of the product life cycle. This finding is to be expected because it is during these front-end activities that eco-innovation is most relevant and effective.

So, there are relatively few tools that explicitly support eco-innovation activities, but why is this a problem? Can design teams not turn to some of the numerous eco-design tools for support when needed? The answer, is 'no', because DfE and eco-design tools do not match the characteristics of an eco-innovative project and can not support the full range of challenges that are likely to be encountered during an eco-innovative project. As

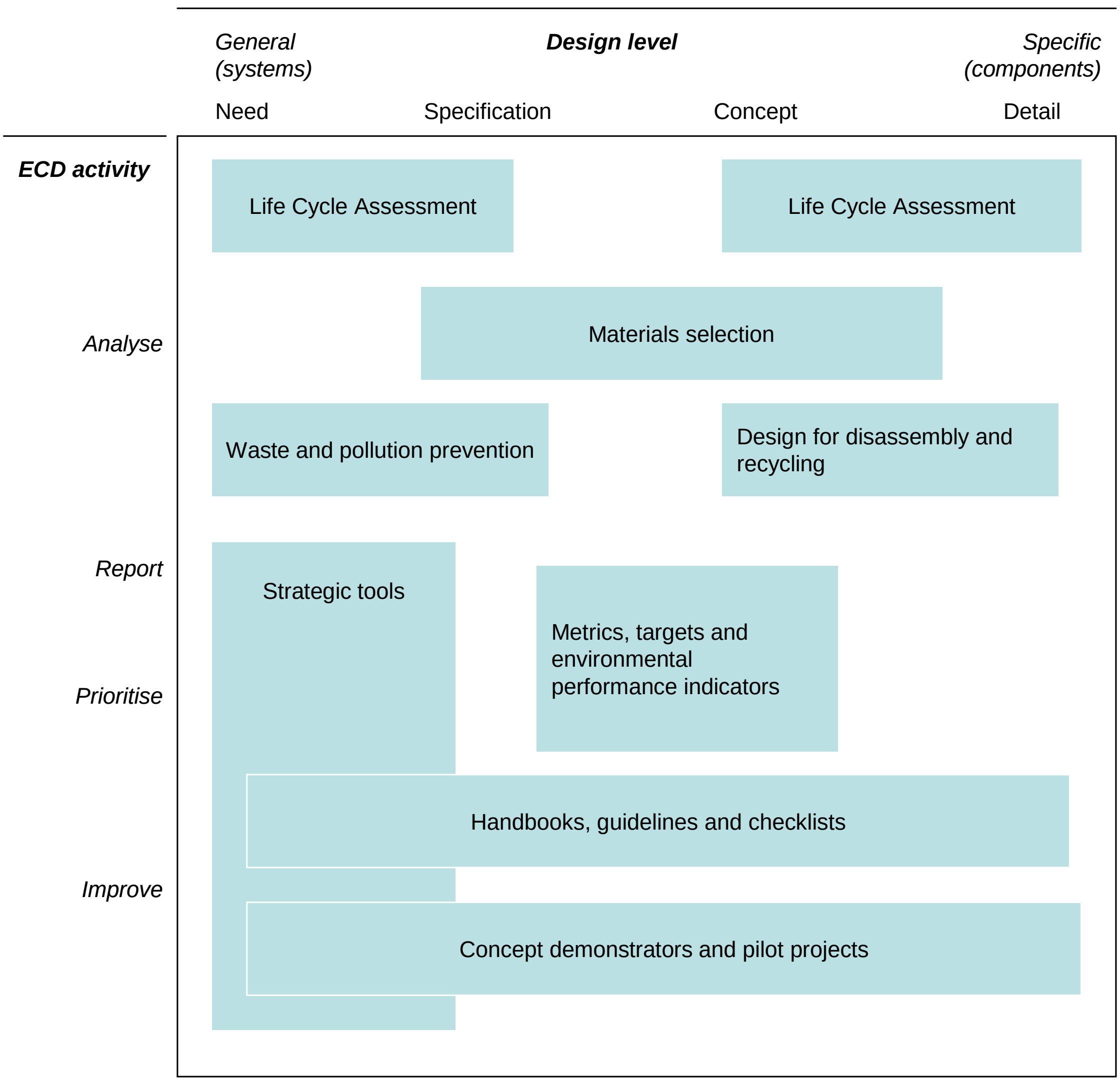

Figure 2.9: Overview of ECD tools with reference to the ARPI framework (Simon et al., 1998)

a reminder, an 'eco-innovative project' was defined as a project that:

- considers the entire product life cycle;
- tackles problems at higher systems levels;
- has a high level of environmental ambition;
- focuses on the activities up to the end of the conceptual design phase.

Hence, although eco-design tools will normally consider the entire life cycle of the product, they generally take the existing solution as the starting point for improvement rather than considering the problem at a higher systems level. DfE and eco-design tools will generally be intended for use after the conceptual design phase and will therefore be less relevant for eco-innovation and may rely on information about the problem or the solution that is not available during the early stages of an eco-innovation project. Finally, DfE and eco-design tools will have a lower level of environmental improvement ambition which may limit the environmental improvements achieved if applied within an eco-innovation project i.e. by encouraging the design team to think about materials compatibility for recycling when they should be thinking about higher-level and more ambitious solutions such as dematerialisation.

This sub-section has established that there are relatively few eco-innovation tools currently available to help design teams with eco-innovation and that there is a need for tools specifically to support eco-innovation because existing DfE and eco-design tools can not support the full range of challenges that are likely to be encountered during an eco-innovative project. In the following sections some of the existing eco-innovation tools are described before considering why these tools are not being adopted by industry.

2.2.2 What examples of eco-innovation tools exist?

In the previous section it was noted that there are relatively few examples of eco-innovation tools. In this section, the availability of eco-innovation tools is assessed.

In order to assess the availability of tools for eco-innovation Table 2.4 was constructed, which categorises the eco-innovation tools currently available according to the type of FEI activity (Koen et al., 2001) they are appropriate for (see Section 2.1.4). The table was populated using the tools deemed suitable for eco-innovation by Gómez-Navarro[3] (2005) and Jones (2002).

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[3] The 'environmental market prospective' and 'sustainability indexes' tools highlighted by Gomez-Navarro *et al.* (2005) have been omitted from Table 2.4. as these tools do not explicitly support eco-innovation and it is not evident why they are considered relevant for eco-innovation. The

Two things are evident from Table 2.4. First, that there are currently very few tools available to support eco-innovation activities. Secondly, of the tools that are available, the majority focus on idea selection. In particular, four out of the five idea selection tools focus on helping to understand or compare the environmental impacts of a product of concept. This observation is consistent with the finding from Baumann *et al.* (2002) who found that, of the 150 ECD tools found in the academic literature, the largest percentage focused on environmental impact assessment. Whilst environmental impact assessment will be an important activity for eco-innovation, there are clearly many aspects of eco-innovation that are not well supported by the current range of eco-innovation tools. There is therefore a case for developing new eco-innovation tools.

Opportunity identification	**Opportunity analysis**	**Idea generation**	**Idea selection**	**Concept and technology development**
Forecasting/ Backcasting (Jakobsen and Ernzer, 2001)	Willingness to pay assessment (EPA, 1996)	PIT diagram (Jones et al., 2001a) LiDS wheel (Brezet, 1996)	Life cycle planner (Kobayashi, 2001) Life cycle modeller (Anderl et al. 1999 in Gómez Navarro et al., 2005) Life cycle costing (Newnes et al., 2008) LiDS wheel (Brezet, 1996) Eco-compass (Fussler and James, 1996)	-

Table 2.4: Categorisation of eco-innovation tools based on the type of FEI activity they are appropriate for

2.3 The problem of poor design tool adoption

This section begins by considering why ECD tools, including eco-innovation tools, often fail to become adopted within industrial practice. It goes on to show that poor uptake of academic design support tools is not a problem limited to the ECD community, and considers some of the literature from adjacent domains. It goes on to present some of the approaches suggested within the academic literature to overcome this problem. Finally, previous work that is relevant to understanding designer's requirements of eco-innovation tools is discussed.

STRETCH approach (Cramer and Stevels 1997) is also omitted as it is a process for ECD rather than a tool.

2.3.1 Why are eco-innovation tools not being adopted?

One of the perennial concerns of the ECD community has been the lack of industry uptake of the many and varied ECD tools that have been generated over the last 20 years (Baumann et al., 2002, Handfield et al., 2001, Luttropp and Lagerstedt, 2006, McAloone et al., 2002). One of the reasons why ECD tools are not being adopted by industry may be the way in which academics develop those tools. Baumann et al. (2002) have provided a useful critique of the academic efforts to develop ECD tools. They concluded that:

> *There were relatively few references that describe the diffusion of ECD methods and tools and experience of how they work in the product development process. Nor do the articles describe how useful the methods or tools are for actually reducing the environmental impacts of products. Finally, most publications with an empirical content report on the testing of new ECD methods and tools and these are often developed in universities and then tested by researchers in a company case study. We conclude that there has been too much ECD method and tool development and too little effort to validate them in practice settings. Those involved in the field are more interested in developing new ECD methods rather than studying the utilization of existing ones in order to evaluate and improve them. (Baumann et al., 2002)*

A wide variety of alternative explanations for the poor uptake of ECD tools can be found within the academic literature. These include:

- *No systematic introduction process* – Tools are often introduced within a company without any formal analysis of the need that the tool is intended to fulfil, with choices about the type of tool and how and when it should be introduced often done on an *ad-hoc* basis (Le Pochat et al., 2007, Ritzén and Lindahl, 2001).
- *Tool not customised to the specific application* – There are many variations in product development activities between companies related to organisational, cultural, process and product differences. These differences may require the tool to be customised to the specific application but this is not normally considered (Le Pochat et al., 2007, Ritzén and Lindahl, 2001, Tukker et al., 2000).
- *No demand* – If there are no environmental criteria in the product requirements specification then quite simply there is no need for eco-design tools (Luttropp and Lagerstedt, 2006, Olundh, 2006).
- *No time* - Environmental impacts are just one of many constraints a designer must consider during product development and hence only a very limited amount of time and effort can be spent on them (Handfield et al., 2001, Luttropp and Lagerstedt, 2006).

- *Designers' requirements not considered* – Tool developers have lacked a thorough understanding of how designers use tools and their main considerations when choosing whether or not to use a tool (Lindahl, 2006). Also, the outputs from tools, such as LCA tools, often require further analysis which requires a certain level of environmental science or ECD knowledge in order to draw useful and sensible conclusions. Unfortunately, design teams, particularly in SMEs, do not have access to this type of expertise (Le Pochat et al., 2007).
- *'Human factors' not considered* – when a new working practice is introduced into an organisation, including the use of eco-innovation tools, there is always a risk that the change will face resistance, at an organisational or individual level (Boks, 2006, Verhulst et al., 2007). This resistance may be due to socio-cultural or psychological reasons rather than technical reasons.
- *Too difficult to understand or apply* – some ECD tools are perceived to be difficult to understand or apply (Handfield et al., 2001, Tukker et al., 2000).
- *Too many tools* – the vast multitude of tools now available makes the process selecting an appropriate tool a complicated and time-consuming task. Designers do not have time to go through such a process and so end up using inappropriate tools, or none at all (Ernzer and Birkhofer, 2002, Knight and Jenkins, 2009).
- *Poor integration* – when ECD activities are treated as a separate stream of activity, distinct from the mainstream product development activities, they struggle to gain acceptance and quickly become marginalised (Lindahl, 2005).
- *Lack of commitment* – design teams are sometimes reluctant to use ECD tools because they believe that their company's rhetoric about wanting to improving environmental performance lacks sincere commitment (Handfield et al., 2001).

In the following sub-section, these explanations for the poor uptake of ECD tools are supplemented by considering some of the reasons cited for the poor uptake of academic design tools in general.

2.3.2 Why are design tools in general not being adopted?

In the previous section a number of reasons why ECD tools, including eco-innovation tools, are not being adopted were suggested. However, this problem is not unique to ECD tools. Across many different areas of engineering design, academics have struggled to get their design support tools adopted in industrial practice. This has led to work investigating why design support tools in general struggle to become adopted.

Based on a combination of a survey and individual interviews, De Araujo (2001 cited in Lindahl, 2005) has identified and listed a number of different reasons for the low level of utilization of design tools in industrial practice:

- *Lack of understanding of the nature of the design tool* – the practitioners are not sure how they can benefit from the available tools.
- *Lack of 'appeal'* – the tool is not customised to the needs of the practitioners.
- *Poor promotion* – poor 'marketing' of different tools.
- *Negative attitude to introduction of new tools* – in many cases based on previous bad experience of tool introductions.

Jänsch and Birkhofer (2007) have also investigated why academic design tools often fail to transfer into industrial practice. They identified three main problems:

- *Representation and documentation problems* – tools are often presented to industrial practitioners in a manner that is too scientific or too abstract.
- *Teaching problems* – the teaching of design tools often lacks sufficient detail about the benefits and properties of the tool, do not include sufficiently-well designed exercises and do not provide sufficient guidance on when or where a tool might be applicable.
- *Acceptance and adaptation problems* – fundamentally, practitioners are often left feeling unconvinced of the benefits of a method and hence they do not use it. Furthermore, if they do try to apply a new tool they often find that a significant amount of adaptation of the tool is required to fit with the NPD process and the team organisation.

From an empirical study based on semi-structured interviews with designers, Lindahl (2006) has added the following additional insights:

- That designers will only use tools if they meet at least one of the following conditions:
    - the tool has been found to be of use for them;
    - the customer requests the use of a particular tool;
    - the tool addresses issues that are encountered on a regular basis;
    - the tool is not experienced as being unnecessarily complicated to use.
- Tools are used to help with communication within the NPD process. Designers are always trying to save time so that they can achieve more. They use tools to achieve this to provide a defined structure that offers benefits like easier exchange of information and easier follow-up and control.

- Designers prefer general guidance rather than overly prescriptive advice, particularly during the early stages of design.

This section has identified some of the reasons why academic design support tools often struggle to gain a place within industrial practice. Reviewing the previous work discussed in this sub-section and the previous one, it would seem that the problem is that design tools must meet the requirements of three different ‘stakeholders’: the tool user (normally a designer), the innovation/NPD process and the organisation. It is understandably a very difficult task for developers of design tools to meet all requirements that these stakeholders place on a tool. Figure 2.10 depicts this problem schematically and highlights the fact that, to a large extent, the needs of the organisation, the process and the user will be inter-related, difficult to neatly separate out and not always aligned. Arguably, the failure of academic design tool developers has been to underestimate or ignore the requirements from one or more of these three stakeholders. This model would suggest that even if the requirements of the user were fully understood and met by the tool, if the tool does not fit within the existing NPD process or does not contribute towards the strategic goals of the organisation, the tool will not be adopted.

It should also be noted in Figure 2.10 that the arrows indicating a set of requirements point in both directions. That is, the tool might place certain requirements on the user, the process or the organisation. For example, there may be a requirement from the tool that the user has at least a basic understanding of the types of environmental aspects associated with a particular type of product. Similarly, there could be a requirement from the tool that the use of the tool be stipulated as part of the innovation/NPD process. Seen in this way, the adoption of a design tool becomes a two-way process, with both the tool and the tool stakeholders needing to adapt in order to ensure that there is a good ‘fit’.

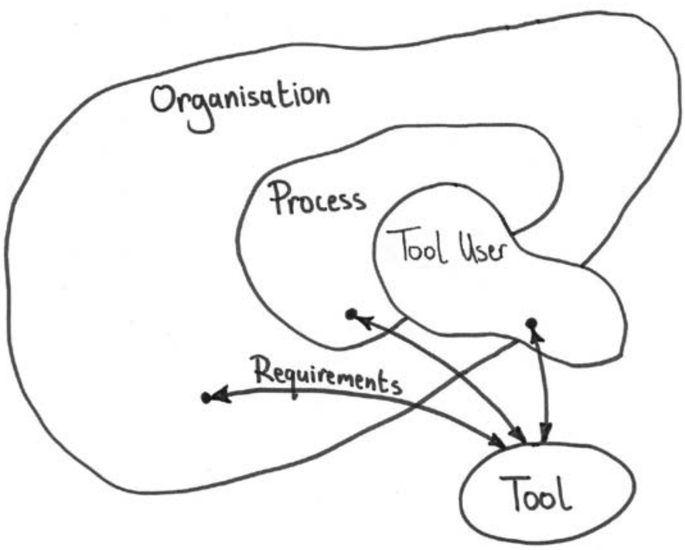

Figure 2.10: Schematic of the key ‘stakeholder’ requirements that a tool must meet in order to be successfully adopted

In the following section, this model is used to categorise some of the approaches being proposed to combat the problem of poor industrial uptake of academic design tools.

2.3.3 Possible approaches to improving the industrial adoption of eco-innovation tools

The previous sub-section concluded that the main causes for the poor levels of design tool adoption within industry were the difficulty in understanding and meeting the requirements placed on the tool by designers, the innovation/NPD process and the organisation. Table 2.5 summarises some of the approaches proposed within the academic literature to increase the industrial adoption of design tools and categorises the approach according to whose requirements the approach focuses on.

Tool user requirements	**Process requirements**	**Organisational requirements**
• Decrease the level of effort required to apply the tool or the complexity of the tool (Geis et al., 2008, Ritzén, 2000, Jänsch and Birkhofer, 2007, Norrell 1992 cited in Janhager, 2005) • Gain a better understanding of the user's requirements (Lindahl, 2006, Jänsch and Birkhofer, 2007)	• Ensure that environmental considerations are integrated within the NPD process* (McAloone, 2000, Olundh, 2006) • Select tools that fit within the NPD process (Knight and Jenkins, 2009) • Carefully select tools that fit the task (Ernzer et al., 2001, Jänsch and Birkhofer, 2007, Schiavone et al., 2008) * specific to ECD tools	• Ensure that the tool is aligned with the strategic goals of the organisation (Le Pochat et al., 2007) • Improve the tool training programme (Jänsch and Birkhofer, 2007) • Use a systematic tool introduction process (Ritzén and Lindahl, 2001) • Customise the tools to the specific company or application (Boks and Pascual, 2004, Jänsch and Birkhofer, 2007, Johansson, 2002, Knight and Jenkins, 2009, Luttropp and Lagerstedt, 2006)

Table 2.5: Summary of the approaches proposed to increase the industrial adoption of design tools

An important point to make about the approaches cited in Table 2.5 is that although many of them are based on insights from industrial practice, the majority have not actually been tested within an industrial setting. It therefore remains difficult to draw conclusions on the efficacy of these approaches. This represents a significant gap in the academic literature.

One of the aims of the research was to investigate the effectiveness of these proposed approaches by testing them within an industrial practice setting. Ideally, all of the possible approaches to improving the industrial adoption of design tools listed in Table 2.5 would have been investigated. However, due to time and resource constraints, it was decided to focus the investigation on three of the approaches that were considered to be the most promising. These were:

User requirements

- Developing eco-innovation tools based on a better understanding of users' requirements.

Organisational requirements

- Using a systematic tool introduction process.

- Customising the tools to the specific company or application.

In the following sub-sections the academic literature relating to these issues is discussed.

2.4 Tool users' requirements of eco-innovation tools

Having selected the approach of developing tools based on a better understanding of the users' requirements this section reviews some of the relevant academic literature.

The most relevant and comprehensive study conducted in this area is the work of Lindahl (2005) who has compiled a list of designers' general requirements for eco-design tools based on a review of academic literature and the analysis of his own interviews with designers about their use of tools. Whilst this work has focused on eco-design tools, it was felt that the requirements would provide a good starting point for understanding designers' requirements of eco-innovation tools as both types of activity are forms of ECD. The requirements identified by Lindhal (2005) are as follows:

- *Integration* – modern approaches to NPD involve parallel activities and a high degree of co-operation between functions. Eco-design tools needs to integrate effectively within this context.

- *Multifunctional team* – eco-design tools need to support and promote multifunctional teamwork and the exchange of information as several authors cite this as key success factor for NPD activities (Wheelwright and Clark, 1992, Ehrenfield and Lenox, 1997).

- *Early phases* – as previously discussed, when ECD activities are conducted in the early phases of the innovation process, there are more opportunities to deliver significant improvements in environmental performance.

- *Time efficient* – lead time is often a concern for innovation activities and so the time to gather input data and apply the tools must not be too long (Ehrenfield and Lenox, 1997).

- *Low quality data* – during the early phases of innovation precise, quantitative data is often not available. Eco-design tools must therefore not rely on this type of data and should be able to work with incomplete or qualitative data instead.

- *Easy to learn, understand and use* – if eco-design tools are too complicated there is a risk that they will only be used by one or two eco-design 'experts'. To facilitate wider adoption amongst the design team, tools must be simple enough to allow eco-design novices to use them effectively (Ritzén, 2000, Le Pochat et al., 2007).

- *Life cycle perspective* – to ensure that the most significant environmental impacts are being targeted for improvement it is important to consider the environmental impacts across the entire product life cycle. Also, if eco-design efforts focus on one phase of the product life cycle there is a risk that any improvements made within that phase will be at the cost of increased impacts elsewhere in the product life cycle. It is therefore important to consider the entire product life cycle (Sherwin and Bhamra, 1999).
- *Marketing aspects* – ECD projects will have to consider the same commercial issues as any other project. In fact, there may be additional challenges associated with marketing if, for example, the product will be sold into not normally served by the company; or if the environmental performance of the product is to be a unique selling point. For these reasons it is important that eco-design encourage the design team to consider marketing aspects.

In Section 6.4.1 the use of this list of requirements as a starting point for understanding designers' requirements of eco-innovation tools is explained.

2.5 Organisational considerations for ECD tool introduction

Boks (2006) and Verhurlst (2007) have argued that one area of ECD implementation that has been neglected is what they refer to as the 'human factors'. They suggest that socio-cultural and psychological factors can play an important part in the success, or otherwise, of ECD implementation activities within an organisation. They therefore propose that new insight into ECD implementation is possible if a change-management perspective is adopted. Whilst organisational issues have been investigated by previous authors (Bhamra et al., 1999, Handfield et al., 2001, McAloone, 2000, Ritzén, 2000, Karlsson, 2001), it is only recently that such issues are being studied as the primary research focus, from a change-management perspective (Verhulst et al., 2007).

This section begins by providing a brief introduction to some of the underlying theory of change management before looking more specifically at some of the literature from within the engineering design domain that has applied this theory to the issue of tool development and adoption.

2.5.1 Change management theory

The ability to adapt in line with developments in technology and the competitive landscape is an essential quality for any modern organisation. There has therefore been considerable academic and practitioner interest in finding ways to effectively manage change within an organisation. How organisational change is managed will depend on the type of change that is occurring. Table 2.6 shows the taxonomy of change provided by Porras and Robertson (1992).

'Order' of change	*Change category*	
	Planned	**Unplanned**
First	Developmental	Evolutionary
Second	Transformational	Revolutionary

Table 2.6: Taxonomy of organisational changes
(Porras and Robertson, 1992)

A 'planned change' is the consequence of a decision taken within the organisation whereas an 'unplanned change' is the consequence of an event or development within the organisation's environment that it must react to.

A 'first-order change' is an incremental change in the organisation whereas a 'second-order change' tends to be a radical, multilevel, discontinuous change resulting in a shift in the fundamental paradigm of the organisation.

From this taxonomy it would seem that the introduction of eco-innovation tools would be best described as a 'developmental' change because it would normally be initiated from within an organisation and, although far reaching in its effects, would not represent a paradigm shift for most companies.

One theory of 'change management' that is appropriate for developmental changes is the 'Unfreeze-Change-Refreeze' model proposed by the psychologist Kurt Lewin's (1943 cited in Burnes, 2004), which has been hugely influential within the field (Burnes, 2004). The model describes three main stages that must occur for a planned change to be successful and enduring:

- *Unfreezing* – people generally prefer to maintain the status quo and can feel uncomfortable when the current situation or ways of working are questioned. This can provide an inertia-like resistance to change which can require significant effort to overcome. The unfreezing stage aims to get individuals within an organisation ready for change by destabilising the current situation (unfreezing) such that undesirable old behaviours can be discarded (unlearn). A wide variety of strategies may be used to achieve this.
- *Change* – during this period the change is implemented. This stage could take a considerable length of time and depending on the specific details of the change and the amount of training required for personnel.
- *Refreeze* – the aim of this stage is to reinforce the change and re-establish a sense of continuity and equilibrium within the organisation. Preventing people from returning to the previous ways of working is one of the key challenges of this stage.

This model of change management dominated thinking on the topic until the 1980's but has received significant criticism in the last two decades. This criticism tends to focus on the conception of change as a linear process and on the organisation as some kind of ice cube. Kanter et al. (1992) argue that these conceptions are 'wildly inappropriate' because 'organisations are never frozen, much less refrozen' and because the stages of change, 'overlap and interpenetrate one another in important ways.' More recent theories of change management have acknowledged that a static view of the organisation in which behaviours are 'frozen' is both unrealistic and undesirable. As Dawson (1994, pp.3-4) comments:

> *'Implementing stability and reinforcing behaviour which conforms to a rigid set of procedures for new work arrangements does not meet the growing requirements for employee flexibility and structural adaptation to the unfolding and complex nature of ongoing change processes. He argues that more recent theories of change management adopt the view that, '…change is a complex and dynamic process which should not be solidified or treated as a series of linear events'*

One aspect of Lewin's work in this field that remains influential is his work on Field Theory. Lewin argued that to in order to understand the behaviour of groups within an organisation: 'One should view the present situation – the status quo – as being maintained by certain conditions or forces' (Lewin 1943 cited in Burnes, 2004). He suggested that these forces interact and combine to create a 'field' and that these fields tend towards a point of equilibrium. It is precisely this equilibrium state that the 'unfreezing' stage of his change management model is trying to disrupt.

From this theory, the method of 'Force-Field Analysis' emerged (Lewin, 1951). Force-Field Analysis diagrams have gained significant popularity amongst change-management academics and practitioners, possibly due to their simple, visual nature, as can be seen in Figure 2.11. The diagram is intended to help with the planning of a proposed change within an organisation. Factors that might encourage the proposed change to be implemented successfully are labelled drivers and are listed down the left side of the diagram. Factors which might resist change or reduce the chances of the change working are labelled barriers and are listed down the right hand side of the page. A weighting is given from one to five to each of the issues to show the significance of the factors with a higher score representing a more significant issue. Force-Field Analysis diagrams were used within this research to help understand the organisational forces driving and preventing the introduction of eco-innovation tools. Their usage within the research is explained further in Section 7.1

Forces FOR change	Strength	Strength	Forces AGAINST change

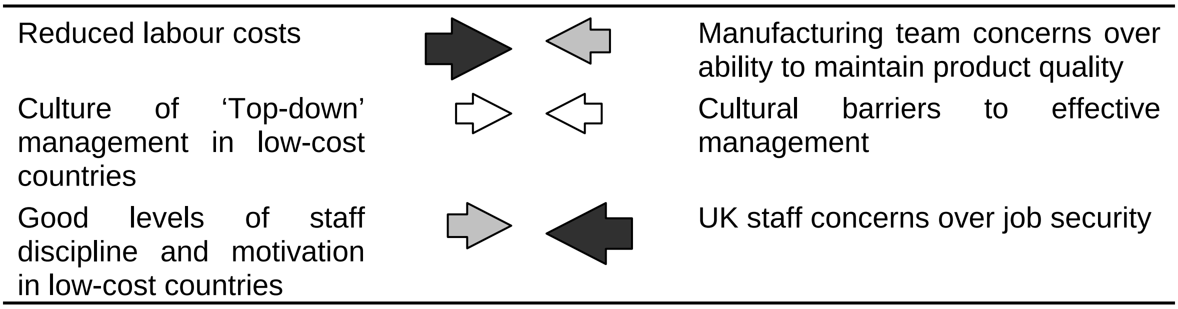

Figure 2.11: Sample of Force-Field Analysis diagram for the change of ‘transferring manufacture to a low-cost country’

Force-Field Analysis is just one of the many tools, methods, models and theories that are available to academics and practitioners trying to understand and manage change within an organisation. In taking a change-management view of the introduction of design or innovation tools academics can benefit from being able to draw upon this extensive body of knowledge. For this reason, change-management theory is now beginning to influence research from within the engineering design domain. This can be seen in the following sub-sections where research which has considered the problem of managing the introduction of a new design or innovation tool is discussed.

2.5.2 Organisational drivers and barriers for ECD activities

One question that several authors have asked, perhaps influenced by change management theory, is ‘what are the organisational drivers and barriers for the introduction of ECD?’ (Boks and Pascual, 2004, Handfield et al., 2001, Johansson, 2002, Tukker et al., 2000, van Hemel and Cramer, 2002).

Whilst investigating the drivers and barriers of ECD was not the main focus, the study completed by Sherwin (2001) is of interest because it specifically looked at eco-innovation. Through his single-case, action research study of the early stages of eco-innovation and the role of product designers, Sherwin noted the following organisational barriers to eco-innovation:

- Management sometimes fail to recognise (and hence fail to utilise) the competencies of product designers that could be very relevant for eco-innovation e.g. generating radical product concept ideas, influencing user-behaviour through design etc.
- Designers may be unwilling to change their ways of working or adapt to the new demands placed on them by eco-innovation.
- The constant pursuit of novelty that exists within innovation-driven organisations is itself a barrier to more sustainable products as it tends to drive consumer demand and artificially shorten product lifetimes.

A more general but more recent study of drivers and barriers to ECD activities was reported by Boks and Pascual (2004) was based on a combination of interviews and questionnaires conducted with large EEE producers based in Japan and South Korea. The study investigated the 'success factors' and 'obstacles' for ECD integration during the early and later stages of the NPD process. The results are presented in Table 2.7.

That customised ECD tools were found to be the most important success factor for ECD integration further justifies the focus of the current research on tools for eco-innovation and in particular on customising tools to meet the needs of the company.

Interestingly, some of the success factors regularly mentioned in the academic literature are absent from these results. In particular, the presence of an environmental champion was not found by Boks and Pascual to be important to integration success.

	Early stages of NPD process	**Later stages of NPD process**
Success factors	1. Customised ECD tools tailor made for the company's needs. 2. The use of environmental checkpoints, reviews, milestones and roadmaps. 3. Good management commitment and support.	1. Environmental issues playing a role in all business activities. 2. Environmental design guidelines, rules and standards very specific to the company. 3. Inclusion of environmental issues in a company's technology strategy.
Obstacles	1. Too big a gap between ECD proponents and those that have to execute it. 2. Organisational complexities, lack of appropriate infrastructure. 3. Lack of cooperation between departments.	1. No demand from the market 2. Lack of environmental goals and vision for individual development projects.

Table 2.7: Success factors and obstacles for the integration of environmental considerations within NPD activities (Boks and Pascual, 2004)

One of the objectives of this research was to investigate the drivers and barriers for introducing eco-innovation within industrial practice in order to help improve the tool introduction process and maximise the chances of long term tool adoption. This aspect of the research is presented in Chapter 7.

2.5.3 Approaches to introducing new design tools

Approaches to the introduction of design or innovation tools have received relatively little attention within engineering design research. This is surprising given the number of tools that are proposed by researchers in this domain and the relatively poor uptake of these tools (Frost, 1999). The introduction of a new design tool is generally a small but significant change for an organisation to deal with. It can represent a significant investment of time, cost and managerial resource for a company. Hence, if the tool is not successfully adopted it represents a significant failure for the organisation. There is therefore an industrial need, and a growing academic interest, in understanding and developing best practices for the introduction of new design tools. In Sections 2.3.1 and 2.3.2 some of the reasons why ECD tools, and design tools in general, have struggled to gain a place within industrial practice were discussed. This work is already producing some useful insights into the phenomenon of tool introduction and how it can be managed more systematically.

Through an interview-based study, Norrell has looked at the introduction of three design tools - Design-for-Assembly (DfA), Failure Mode and Effect Analysis (FMEA), and Quality Function Deployment (QFD) - across six different Swedish manufacturers (Norell, 1993). She found that the uptake of a new tool was generally good during the main activities of an introduction project (Phase 1 in Figure 2.12). However, after the completion of an introduction project (point A in Figure 2.12) the usage of the tool tended to either pick-up significantly as the tool is rolled out across the entire company, or, more commonly, decline to almost zero usage. Companies tend to assume that if the pilot study has been successful, the introduction of the tool is all but done. Unfortunately this model shows that this is not the case and that further work is required if the tool is to become a long-term success.

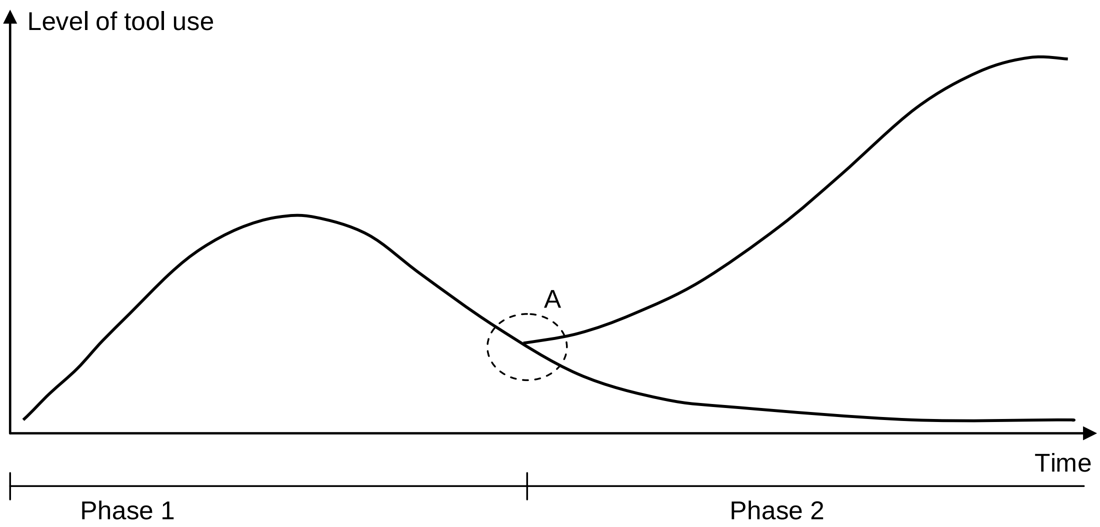

Figure 2.12: A model of the usage of design tools over time (Norell, 1993)

Since Norrell's early work, several researchers have investigated the introduction of design tools (Beskow et al., 1998, Lindahl, 2005, Ritzén, 2000). Based on their combined experience of change management within NPD activities (Ritzén, 2000) and understanding designers' requirements of design tools (Lindahl, 2005), Ritzen and Lindahl (2001) have proposed a best-practice model for the introduction of design tools (Figure 2.13).

The tool introduction process begins at the point when an organisation has identified the need for a tool and selected an appropriate tool to meet that need based on the tool selection procedure described by Ritzen and Lindahl (2001) or by some other process. For the systematic tool introduction to begin, a formal decision must be taken to introduce the tool – the *initiation.* After this, there are three main stages to the process:

- *Preaction* – This planning stage is used to: more precisely define the need that the tool must address; clarify the scope of the project (i.e. is the tool being introduced across

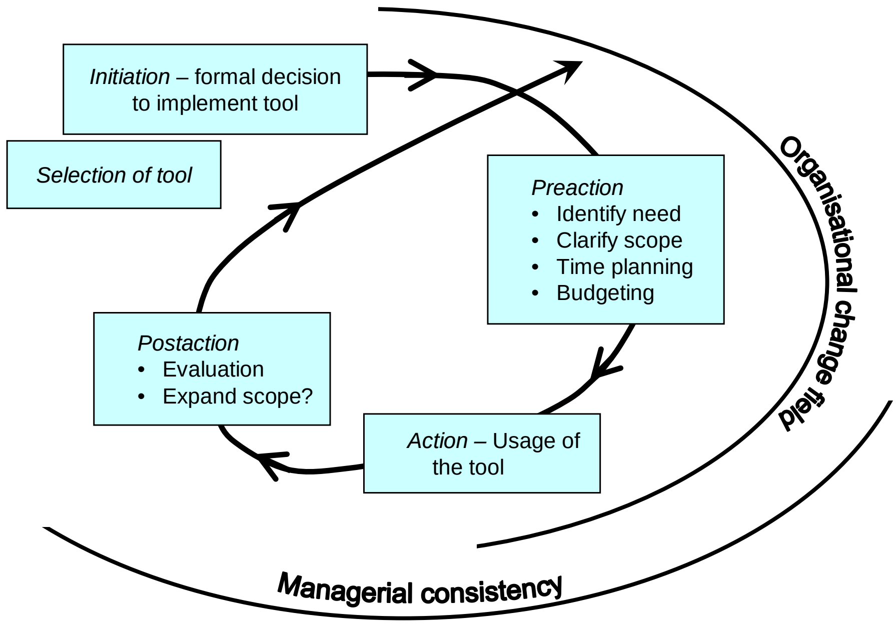

Figure 2.13: The first cycle of the tool introduction process proposed by Ritzen & Lindahl (2001)

  the whole company or just one design team?); and estimate the time, budget and resources required for the project.

- *Action* – The plans to introduce the tool made in the previous stage are executed.

- *Postaction* – The main feature of this stage should be a thorough evaluation of the tool introduction. The content of the evaluation will vary according to the aims the company had when electing to introduce the tool. The final activity should be a decision as to whether a new cycle of introduction should go ahead or not (i.e. having introduced the tool within one design team, should the scope of the introduction increase to include the whole organisation?).

Throughout each of these stages there are two other aspects which must be considered. First, the 'organisational change field'. This refers to Lewin's work on Field Theory described in the previous section. The practical implication within this model is that at all stages the team must bear in mind who will be affected by the tool introduction, how they might react to this type of change, and what can be done to reduce any resistance to the tool introduction.

The second consideration is 'managerial consistency'. This emphasises the need for managers to engage in the tool introduction process – setting goals, monitoring progress and giving feedback. This type of management activity, if maintained throughout the project, helps to demonstrate management commitment to the change and ensure that the project receives the necessary resource.

The strength of this model is that it draws upon theories of change management, for example the cyclical model referring to the dynamic view of the organisation and the need for continuous improvement, both of which are considered important within change management literature currently. It is also a very practical model, which, with some further thought, could be used by practitioners involved in managing change to guide their work. However, one area in which this model does not provide adequate practical advice detail is in the management of the organisational change field. This is an area that is explored further within this research through the use of Force Field Analysis. The conclusions from this work are presented in Chapter 7.

Whilst the tool introduction model proposed by Ritzen and Lindahl has drawn on empirical insights, there are no accounts available of this process being applied within an industrial setting. This makes it difficult to evaluate the accuracy and effectiveness of this model. However, the academic literature does contain at least three accounts of attempts to introduce ECD tools in a structured manner (Knight and Jenkins, 2009, Luttropp and Lagerstedt, 2006, Schiavone et al., 2008). As these studies feature tool customisation as a major part of the introduction process they are discussed in the following section which focuses on the topic of tool customisation as an approach to increasing tool adoption.

2.5.4 Customising ECD tools to improve adoption

Recent work on the introduction of ECD tools has suggested that customisation of the tools to the requirements of the designer, the NPD process or the organisation in which they are to be applied might improve their chances of being adopted in the long term (Knight and Jenkins, 2009, Luttropp and Lagerstedt, 2006, Schiavone et al., 2008). This section considers three examples of industrially-based research that have investigated this tool customisation strategy.

Luttrop and Lagerstadt (2006) have distilled and summarised many of the eco-design guidelines found in the academic literature and industrial practice into what they call 'The Ten Golden Rules'. The Ten Golden Rules were introduced within a multi-national producer of transport equipment. A short manual was produced for the company which included The Ten Golden Rules along with space next to each rule to allow designers to write-in customised versions of each rule. Customising the tool in this way was intended to make the tool more relevant and more applicable to the specific tasks of the individual designer. This solution also neatly managed the conflict between the central management who wanted eco-design applied in a consistent manner across the company and the individual designers who faced significantly different eco-design problems and therefore needed very different guidelines. Some of the other considerations that figured in the development of the customised version of the tool discussed by Luttrop and Lagerstadt were:

Time and space – The guidelines had to be quick and easy to understand. The manual was limited to four pages of A4.

Language – Some of the terminology used within The Ten Golden Rules was adapted to match terms that were in common usage within the company.

Ease of recall – Each guideline was accompanied by a cartoon icon to help designers to remember them.

Vezzoli and Sciama (2008) have also proposed a process for customising eco-design guidelines to the needs of the company and have reported on an industrial trial of the process with a vending machine manufacturer. The customisations were based on the results of a full LCA conducted on one of the company's products; and a good understanding of the product to which the guidelines would be applied. The guidelines and a supporting manual were introduced to the company through a workshop and feedback from the company was used to produce a second iteration of the guidelines. Whilst the authors cite integration of the guidelines with the company's existing NPD process and a good understanding of the company and its culture as key to the successful introduction of DfE guidelines, they provide little detail on how this can be achieved. One disadvantage of the approach taken by Vezzoli and Sciama is that it required significant input from the academic research team, both in conducting a full LCA of a product and in customising the guidelines. Unfortunately many companies will not have access to this level of academic support which may make this approach difficult to implement for a company.

A useful contribution has been made by Knight and Jenkins (2009) who have described their attempt to introduce a range of eco-design tools within Smiths Detection, a medium-sized international manufacturing company. One particularly interesting aspect of this work is that the lead researcher was an employee at Smiths Detection during this project and hence this study gives a practitioner's perspective of the introduction.

The approach for the project is summarised by Knight as:

Applicability = Compatibility + Adaptation[4] *+Validation*

The project began with Knight selecting 15 eco-design tools from the academic literature that appeared to be relevant to the needs of the company. The compatibility of these tools was more formally investigated through a focus group discussion on the short-listed tools

[4] What Knight and Jenkins refer to as 'adaptation' equates to 'customisation' within the parlance of this research.

by a range of competent staff representing all levels of the organisation. The 15 tools were ranked in order of preference by this group and three tools were selected to be introduced within a pilot project: eco-design guidelines, eco-design checklists and the MET Matrix (Brezet and van Hemel, 1997a). These tools were then adapted by a group of lead-users within the organisation. Adaptations included compiling custom eco-design checklists and changing the terminology used within the tool to match the terms in common usage within the company. Finally, the tools were validated by applying them to a case-study product.

Knight attributes the success of this project in part to the, 'choice of flexible tools with which the design staff could readily empathise'. Guidelines, checklists and evaluation matrices are commonly used by designers for other design considerations and hence these tools were readily adopted.

One interesting point to note is that in the projects discussed by Lagerstadt and Luttrop and Knight the tool customisation was completed to a large extent by the designers themselves whereas in the case of Vezzoli and Sciama it was done by the academic research team. Whilst all three projects claim that the tool introduction activity was successful (although there was no formal review in any of these projects) Knight believed that the involvement of the designers in the tool customisation activities was an important feature of the project which had ensured the acceptability of the tools to the design community within the company.

2.6 Summary

This chapter began by considering what eco-innovation is. Working definitions of an *eco-innovative process* and an *eco-innovative product* were developed and the concept of eco-innovation was given further context by placing eco-innovation relative to other forms of ECD and existing models of NPD and innovation. Section 2.2 gave a brief overview of the types of general ECD and eco-innovation tools currently available. Section 2.3 introduced the problem of poor design tool adoption, looking at the explanations for this found within the ECD literature and more generally within the engineering design literature. Finally, Section 2.4 summarised some of the approaches which have been suggested for improving the industrial adoption of ECD tools which might be relevant for eco-innovation.

The main points taken forward from this chapter are:

- An eco-innovative project is defined as a project that:
    - considers the entire product life cycle;
    - tackles problems at higher systems levels;
    - has a high level of environmental ambition;

    - focuses on the activities up to the end of the conceptual design phase.
- An eco-innovative product is defined as, 'a product that results in significantly less environmental harm than the use of relevant alternatives'
- The main activities within the early stages of innovation are:
    - Opportunity identification
    - Opportunity analysis
    - Idea generation
    - Idea selection
    - Concept and technology development.
- There is a dearth of tools available for eco-innovation, and of those that are available, the majority focus on environmental impact assessment.
- The causes of poor ECD tool adoption can be related to failures of the tools in meeting user, process or organisational requirements (or vice-versa).
- A number of approaches to improving tool adoption (including ECD tools) have been proposed but few of these have been tested within an industrial setting – this represents a significant gap in the existing academic literature.
- Principles drawn from change-management literature offer many ideas to improve long-term tool adoption.
- This research has chosen to focus on the industrial testing of the following four strategies:
    - Developing tools based on a better understanding of users' requirements.
    - Ensuring that environmental requirements are integrated within the early stages of innovation.
    - Using a systematic tool introduction process.
    - Customising the tools to the specific company or application.

3 Methodology

Not everything that can be counted counts and not everything that counts can be counted. (Albert Einstein)

This chapter outlines the main research activities completed in pursuit of answers to the research questions and describes the methodological decisions and issues encountered. Section 3.1 describes the philosophical foundations of the research and how this influenced the choice of the research methodology. Section 3.2 reviews four possible research methodologies before defining and justifying the final methodology chosen. This in turn allows the research questions to be formally defined in Section 3.3. A brief overview of the research activities completed is presented in Section 3.4 in order to relate the research questions to the activities, and to give the reader an understanding of the activities prior to discussing some of the more specific issues associated with data collection (Section 3.5) and data processing and analysis (Section 3.6). Section 3.7 provides a summary of the chapter.

3.1 Philosophical foundations of the research

This section attempts to briefly explain the authors 'view of the world' and explain how that has affected the choice of research approach, the research questions, the methodology and the methods used with the research. This is important as it has consequences for the standards of judgement for the research.

In Section 1.4.1 the research problem was formulated as follows:

This research aims to understand how eco-innovation tools can be developed and introduced to a company such that they are adopted into the long-term practices of the company and contribute to the development of eco-innovative products.

The 'practices' of interest in this case are the design and innovation processes. These processes involve human actors engaging in what are fundamentally social activities. It is therefore logical to turn to the philosophy of social science, rather than the philosophy of natural sciences, when looking for guidance on ontological, epistemological and methodological issues.

The philosophical foundation for the current research is 'realism', which draws on aspects of both positivist and constructionist philosophy, as explained by Robson (2002):

[Realism] permits a new integration of what are usually referred to as subjectivist and objectivist approaches in social theory. The former approaches emphasize that action is meaningful and intentional, that it is

social behaviour, that meanings are social meanings, and that intentionality involves reflexive monitoring of conduct in a social milieu. However, they have tended to deny an objective character for society. Objectivist approaches, while emphasizing the reality of society, tend to deny the causal role of agency.

The aim of science within the realist philosophy is to invent theories to explain the real world, and to test the theories by rational criteria. This is done by exploring the *mechanism* by which an *action* leads to an *outcome* within a certain *context.* This is shown schematically in Figure 3.1 in which the action of applying a flame to gunpowder leads to the outcome of an explosion. Note that in certain contexts this mechanism may not occur e.g. if the gunpowder is damp, if there is no oxygen present etc.

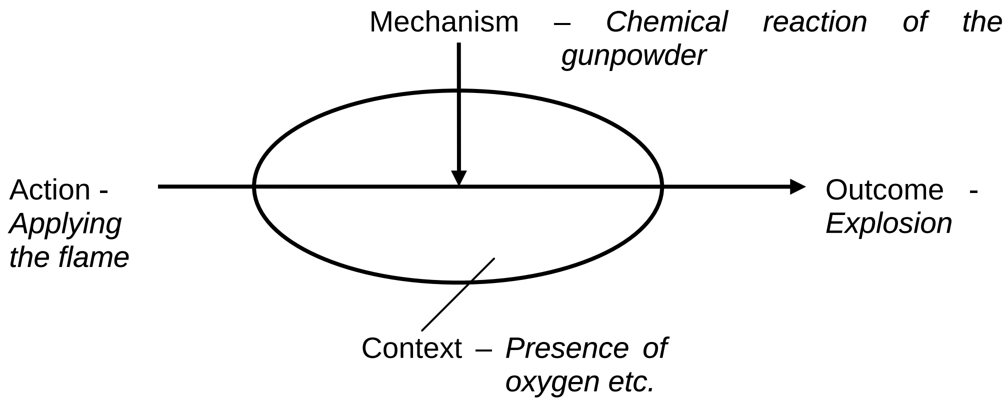

Figure 3.1: Representation of the realist explanation

The aims of this research can be expressed using this model, as shown in Figure 3.2 Here the action is the introduction of an eco-innovation tool; the mechanism is the customisation of the tool to the context (the design team and organisation in which the tool is being applied); and the outcome is that the tool is adopted.

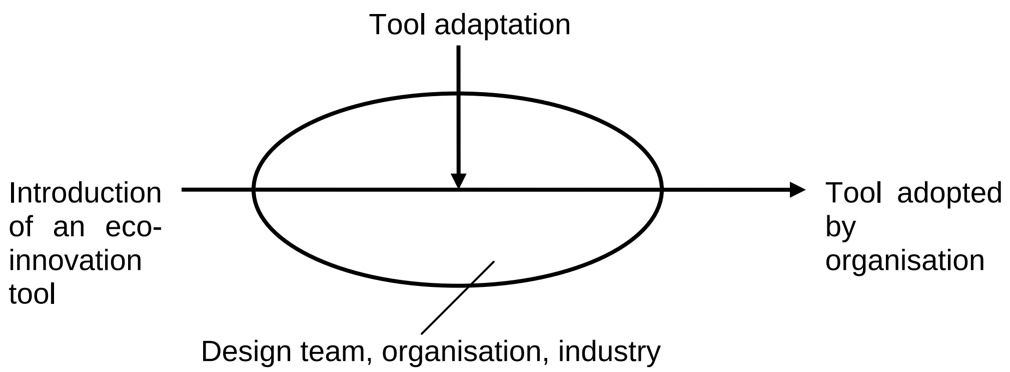

Figure 3.2: Proposed realist model of eco-innovation tool adoption

A realism perspective was chosen for this research for the following reasons:

- The research is investigating a problem set in a social milieu, involving human agents with subjective motivations – a type of problem for which a pure objectivist paradigm would be less effective as it ignores the ability of humans to reflect on problems and act on these in an interdependent way (Robson, 2002).
- There is relatively little theory on how tools are customised and adopted and therefore the research aims to generate new theory on these issues as well as trying to test existing theories. An objectivist view is useful for theory testing but less useful for theory generation where a realism view is more appropriate.
- Because there were no known, 'live' cases of eco-innovation tools being introduced or customised at the time of the research, it was necessary for the researcher to instigate and participate in such activities. This type of researcher participation is not consistent with objectivist approaches such as positivism that maintain that the researcher must remain detached from the research subject and observe behaviour 'through a one-way mirror'.
- Finally, constructivist and critical theory approaches from the more pure end of the subjectivist scale were dismissed as the researcher's personal belief is that there is a real world independent of our consciousness of it - something that is denied by these viewpoints.

This section has briefly outlined the philosophical foundations for the research. As the research has thus far only been defined at an ontological/epistemological level, the following section reviews the possible research methodologies before defining and justifying the research methodology selected.

3.2 Review of possible research methodologies

Having established that the philosophical foundation of the research is the realism perspective, the next step is to establish the methodology for the research. A 'methodology' can be defined as 'a body of methods, rules and postulates employed by a discipline: a particular procedure or set of procedures' (Merriam-Webster Online Dictionary, 2010). There are two important points that emerge from this definition. First, that each discipline has its own set of methods which are deemed to be acceptable. Therefore in reviewing research methodologies in the following sub-sections specific comments are made concerning the acceptability of the methodology within the engineering design community. Secondly, it implies that a methodology should provide a procedure for the research activities. The author would argue that due to the large range of possible research topics and approaches it is very difficult to define a generally applicable 'procedure' *per se* for research, even within a single discipline. Instead, the researcher's personal interpretation is that a methodology should provide a strategy or a logical framework which a researcher can then draw upon to guide key decisions about the types of method to employ for data collection, processing and analysis. This is not dissimilar to the view expressed by Blessing (2002) who states that a design research methodology, 'should help in identifying research areas and projects, and in selecting suitable research methods to address those issues.' After reviewing these methodologies, the actual methodology for the current research is defined and justified.

3.2.1 Design experiments

Design experiments attempt to apply the positivist principles of the 'Scientific Method' developed within the natural sciences and apply them within the engineering design domain. Wallace and Blessing (2000 cited in Blessing and Chakrabarti, 2009) suggest that design research is currently within an 'Experimental' phase, having previously passed through an Experiential phase (senior designers describing their experience of product development), and an Intellectual phase (academics proposing methodologies, principles and tools). A significant amount of current research in engineering design is based on some sort of design experiment. A typical example of this approach is the study undertaken by Jones (2002) who investigated the effectiveness of eco-innovation tools using design experiments conducted with undergraduate engineering students. Some of the features of this work drawn from a positivist tradition include:

- the use of a 'control group';
- the use of exactly the same design brief in both the control and experimental groups;
- an attempt to control for participant variables such as design experience;
- and the avoidance of participation by the researcher.

There have also been attempts at conducting design experiments within an industrial setting using real-life design teams. Howard (2008) studied the affect of various types of information stimuli on the design output of a packaging design team within their normal industrial setting. However, this work could be better described as quasi-experimental as participant variables could not be controlled and the design brief varied between control and experimental groups.

These examples demonstrate the type of conflict faced by researchers trying to balance, on one hand, the desire to follow one of the established models of experimental design, whilst on the other, wanting to conduct the research in a context that is as 'realistic' as possible in terms of the environment, the participants and the task.

A related but distinct problem with design experiments is the risk of results being biased by the 'Hawthorne effect.' The effect was first noted by Roethlisberger and Dickson (1939) during research at the 'Hawthorne' factory who concluded that in some cases worker productivity had improved simply in response to the fact that they were being studied and the special social conditions associated with that, not in response to any particular experimental manipulation. It has since been used as a generic term to describe many forms of positive result or change in subject behaviour which are attributed to subjects being aware of being studied (Jones, 1992).

Some of the possible benefits of using a design experiment approach to investigating the introduction of eco-innovation tools would be:

- *Improved claim to 'internal' or 'construct' validity* – following a design experiment allows the researcher to draw upon a range of tactics developed within the positivist tradition for reducing bias stemming from the researcher or the participants.
- *Repeatability* – following a highly structured experimental protocol should enhance claims to the repeatability of the research activities.
- *Acceptability of results within the research community* - as mentioned previously, design research is within an 'Experimental' phase and hence it will be easier for the research community to evaluate the quality of the work and, all being well, accept the findings.

Some of the problems of using a design experiment approach investigating the introduction of eco-innovation tools would be:

- *Risk of Hawthorne effect* – in trying to establish a controlled environment in which to perform an experiment unnatural behaviour may be elicited in the participants.
- *Theory-testing not theory-building* - There is relatively little existing theory on why eco-innovation tools are not adopted by design teams or how to customise eco-innovation tools. The strength of design experiments is in theory testing, not theory-building.
- *Difficulty in investigating contextual factors* – In the previous section it was noted that a realism viewpoint acknowledges that a *mechanism* may fail to activate if the contextual conditions are not appropriate. Part of the stated aim of this study is to understand what contextual factors may affect the adoption of tools. Design experiments would not be an appropriate methodology for investigating such issues.
- *Reductionism not appropriate* – related to the previous point, experiments, including design experiments, assume that the behaviour of a system can be explained if the behaviour of the individual parts is understood e.g. the whole is equal to the sum of its parts. However, due to the complexities of social 'systems', which are 'not homogenous through time' (Keynes 1938 cited in Checkland and Holwell, 1998), this assumption may not be valid (Checkland and Holwell, 1998). Hence the findings from testing eco-innovation tools within a design experiment in a controlled situation may not be useful

in predicting the success or otherwise when the same tool is introduced to the organisation as a whole.

In summary, design experiments are likely to be useful for understanding the performance of an eco-innovation tool, but would not help to understand some of the complex social issues surrounding tool adoption by an organisation.

3.2.2 Design Research Methodology (DRM)

It has previously been suggested that design research has had relatively little impact on industrial design practice (Blessing and Chakrabarti, 2009, Frost, 1999). Blessing and Chakrabarti (2009) suggest that one of the main causes of this failure to be a lack of rigour in design research. They therefore propose that by adopting a more formal methodology for design research, the ability of the design research community to both explain and support design practice will be enhanced. Design Research Methodology (DRM) is the result of their attempt to develop such a methodology.

The main stages of DRM, depicted in Figure 3.3, are:

Research clarification – a detailed literature review to identify factors that may have a significant influence on the issue of concern (e.g. 'what factors affect the time-to-market of products within this company?')

Descriptive study I – an initial study, often based on qualitative methods, is undertaken to explore with design practitioners the issues identified from the previous phase. The result of this activity is a more accurate understanding of problem. This understanding may be formulated into a 'Reference Model' that details the range of influencing factors being considered and makes explicit the relationships, either assumed or proven, between these issues (e.g. spending time on modifications later in the design process was found to be a cause of increased time-to-market and this was found to be due to poor problem definition.)

Prescriptive study I – during this phase a detailed description of the desired situation is developed and an 'Impact Model' is created which, in a similar manner to the Reference Model, shows how making an improvement in one or more influencing factors could lead to the achievement of the desired situation. This model is used to guide the development of a design 'support'. The support could be a new tool or method that aims to provide a practical benefit within the areas targeted by the research (e.g. to improve problem definition a checklist was developed that aimed to ensure that the problem definition was comprehensive and robust.)

Descriptive study II – once the support is developed it is tested in two ways. First, the support must demonstrate that it has the desired effect on the 'key influencing factor' that it was intended to have (e.g. does using the checklist lead to higher quality problem

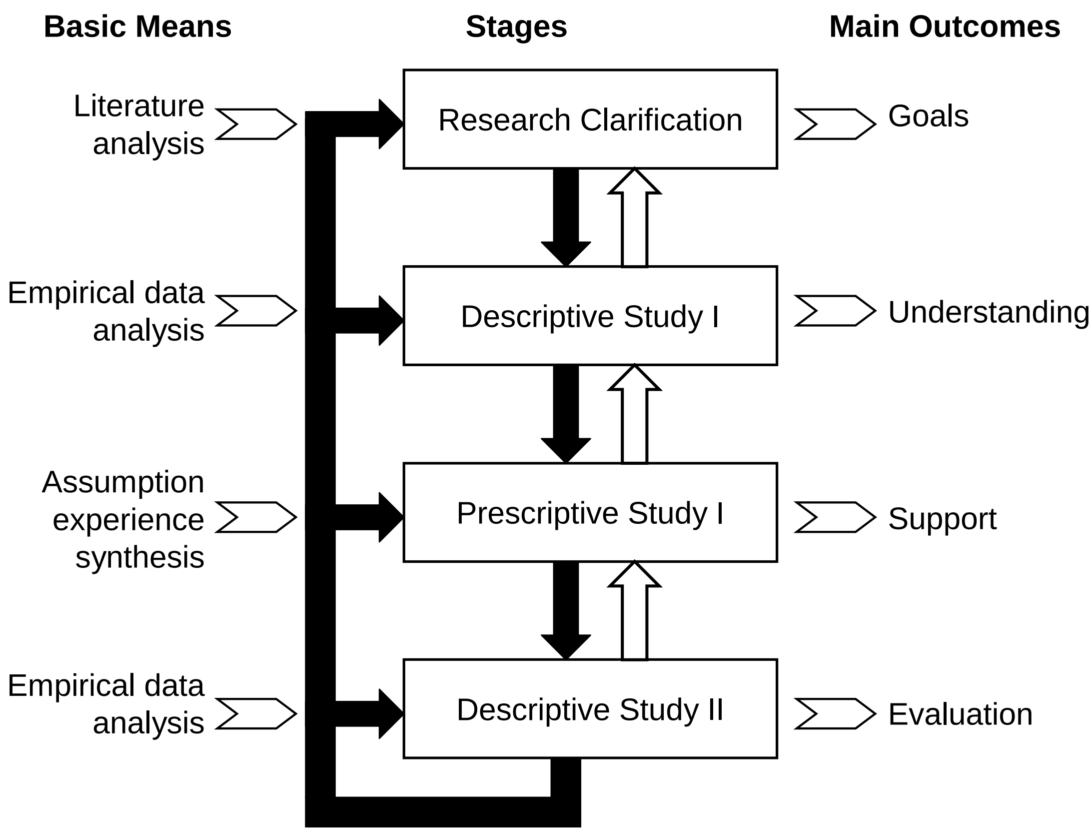

Figure 3.3: Overview of the Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009)

definitions?). If this is proven, the second test is to demonstrate that the introduction of the support has led to improvements in the problematic situation (e.g. has the improved quality of the problem definitions led to less time being spent on modifications later in the design process, and in turn has this led to reduced time-to-market?).

Some of the advantages of adopting the DRM approach when investigating the introduction of eco-innovation tools would be:

- *Relevance for design research* – because it has been developed specifically for design research the advice given is highly relevant and does not have to be 'interpreted' for use in design research as other methodologies taken from the social sciences often have to be.
- *Acceptance of findings within the research community* – whilst there are some critics of DRM (see points below), the use of DRM, particularly amongst European doctoral students in engineering design, is increasing and hence it will be easier for the research community to evaluate the quality of the work and, all being well, accept the findings.
- *Focus on improved practice* – DRM aims to tackle problematic situations and therefore contribute to improvements in design practice as well as improving the understanding

of design practice. In particular, the methodology is aimed towards the evaluation of new tools or methods – this fits with the aim of the current research.

- *Flexible approach* – whilst described in a very neat and linear fashion here, the authors accept that in reality there may be iterations between the different phases and that the entire process may not be completed.

The DRM has been critiqued by Eckert *et al.* (2004) who note the following relevant criticisms:

- *Quantitative measures are not always useful* – the complexity of a human activity system cannot always be reduced to a limited range of quantitative measures (Checkland, 1981) and yet this is always the aim of DRM.
- *Quantitative measures formulated too early in the research process* – As the outcomes of a piece of research or intervention can not always be foreseen, the emphasis in the early stages of a research project should be on questions, not the measurement of outcomes.
- *Focus on quantitative measures can draw attention away from important issues* – The focus on quantitative measures, 'may distract attention from what is really going on' (Eckert et al., 2004 pp.24). The researcher must be alert to the many subtle and unintentional changes that occur within the design process being observed which may be better understood using qualitative methods rather than quantitative measures.
- *Lack of experimental control not accounted for* – whilst design experiments with engineering students can be controlled sufficiently to obtain statistically significant data (e.g. by controlling for experience, modules taken, control groups, large number of repeat experiments), the same is rarely achievable within an industrial setting. This is a major concern for research that aims to evaluate the effectiveness of new tools or methods and is not sufficiently dealt with by the DRM methodology.

3.2.3 Case study

Yin (2003) has defined a case study as:

> *An empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.*

Originating from the social sciences, the case study methodology has been popular in social policy and management research for several decades. Whilst there are many variations of case study research, case studies generally involve an in-depth study of an organisation or several organisations with the purpose of *exploring* phenomenon, *describing* phenomenon, or *explaining* phenomenon (Yin, 2003). Existing theory is often used to guide the development of research questions, and hence the type of case study. The research team may draw upon both qualitative and quantitative sources of data and will often use a variety of sources of evidence including interviews, document studies, observations etc.

Case study research struggled for some time to be recognised as a legitimate form of inquiry, possibly due to the fact that it sits somewhere between the positivist and constructionist philosophies. The most notable exponent of case study research is Yin (2003) who claims that the case study approach is ‘an all-encompassing method – covering logic of design, data collection techniques, and specific approaches to data analysis’. Yin’s descriptions of the case study approach have done much to legitimise it as a distinct and valid methodology.

Yin’s contribution to the case study methodology has been particularly focused on increasing the rigour, validity and generalisability of findings from case studies. In discussing these issues, it becomes clear that Yin’s view of the world is more closely linked to a positivist viewpoint than a constructionist one. In contrast, authors such as Stake (1995) are less concerned with generalisability and focus instead on the role of the researcher as an agent for change within the problematic situation being investigated. In this way, Stake’s approach to case studies shares some similarities to Action Research which is discussed in the following section.

Another author who has made a significant contribution to the case study methodology is Eisenhardt who has outlined a process for building theory from case study research (Eisenhardt, 2002). This process draws on much of Yin’s work but also incorporates aspects of Grounded Theory (Glaser and Strauss, 1967) and the specific techniques for analysing qualitative data described by Miles and Huberman (Miles and Huberman, 1984). The specific influences from Grounded Theory include beginning the research with only broad areas of interest rather than using a detailed review of the literature to define very specific research questions, thereby avoiding the definition of specific research questions in order to retain ‘theoretical flexibility’. Later in the process, the researcher is encouraged to overlap data gathering and data analysis activities such that interesting lines of inquiry can be further explored and less fruitful aspects abandoned. Influences from the qualitative data analysis work of Miles and Huberman include the use of tabular displays of evidence to help search for patterns and evaluate the evidence supporting a hypothesis. New elements of the process introduced by Eisenhardt include a recommendation to use multiple researchers to strengthen the validity of findings by promoting new insights (and potentially conflict) from the comparison of different views, as well as an emphasis on comparing research findings with existing literature in the final stage of the process. The process presented by Eisenhardt therefore represents an interesting synergy of these three approaches which together provide a well-defined process for generating theory from case studies.

Some of the advantages of adopting a case-study methodology when investigating the introduction of eco-innovation tools would be:

- *Suitability for studying industrial practice* – Because it has been specifically developed for examining problems within their normal social context, case-study methodology is very suitable for understanding and comparing industrial practice.
- *Well-developed strategies for improving the rigour and validity of findings* – Mainly thanks to the work of Yin, there is extensive literature explaining how case study research studies can be designed, executed and the resulting evidence analysed to ensure the rigour and validity of the findings.
- *Well-defined process for theory generation* – the work of Eisenhardt provides a useful process that should help to generate new theory from case study research.
- *Ability to deal with both qualitative and quantitative data* – Mixing these two different types of data sources is common with case study work and can often be strength of the approach if it is part of a systematic effort to triangulate findings.

Some of the disadvantages of adopting a case-study methodology when investigating the introduction of eco-innovation tools would be:

- *Concerns over validity and generalisability* – within the social sciences, concerns have been raised about the validity of the case study approach and the generalisability of the findings derived from such approaches (Robson, 2002). However, many of these criticisms have now been answered (Flyvbjerg, 2006) and case study methodology would now appear to have been recognised as a legitimate form of inquiry.
- *Potential for confusion* – although the term ‘case study’ is seen frequently in research papers originating from the engineering design domain these tend to be refer to the application of a new tool to a ‘case study product to help prove the validity of the approach. There is therefore potential for confusion when trying to disseminate the findings of research based on case study methodology within the engineering design domain.

3.2.4 Action Research

Action research is a methodology originating from within the social sciences which aims to study problems within their normal environment and context. Kurt Lewin’s work on minority problems in the 1940s is recognized as the first example of Action Research but since then a significant range of different approaches have emerged including ‘Action

Science' (Argyris, 1995), 'Participatory Action Research' (Whyte, 1989) and 'Collaborative Inquiry' (Reason and Bradbury, 2007).

The commonality across these different approaches, and the thing that distinguishes Action Research from other methodologies such as case studies and ethnography, is that the researcher is expected to actively engage with the research participants in order to develop a solution to the problem being studied. This is clearly expressed within the definition of Action Research provided by Rappoport (1970):

> *Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually accepted ethical framework.*

The process of Action Research is often described as an iterative cycle of action and reflection, as depicted in Figure 3.4.

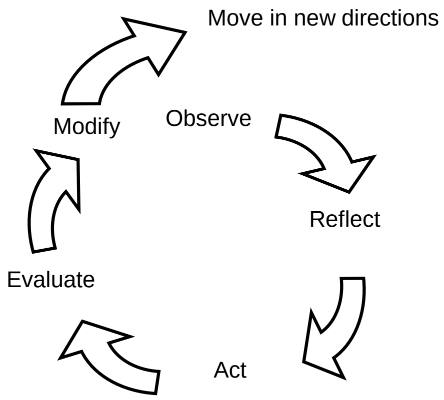

Figure 3.4: Action Research action-reflection cycle after McNiff & Whitehead (2006)

Reflection is important within Action Research in two ways. First, there is reflection on the problematic situation in general, as shown in Figure 3.4. Secondly, there is reflection on the researcher's or practitioner's own behaviour and their role within the problematic situation. In particular, the researcher/practitioner must reflect on whether they are acting and living in accordance with their beliefs and values. If not, they may experience themselves as a 'living contradiction' (McNiff and Whitehead, 2006). Interestingly, reflexivity is seen as one of the features of Action Research that helps to increase its validity and rigour, as by encouraging the researcher to constantly examine and question their behaviour and assumptions the researcher is more likely to recognize the impact of them as an individual, with a particular social identity and background, on the social situation being studied, and the potential sources of bias in their interpretations of what they encountering (Ahern, 1999).

This leads us into the wider question of how meaningful, valid and robust findings can emerge from a process in which the researcher is highly engaged and is actively trying to influence towards a ‘positive’ outcome. Much of the criticism of Action Research stems from comparisons with the ‘scientific method’ of the natural sciences (Susman and Evered, 1978). One of the main criticisms has been that Action Research is not replicable. However, as Checkland (1998) notes, the problem with trying to apply the scientific method within design research is that it was never intended to be applied to phenomenon that are ‘not homogenous through time.’ Clearly, design practice is an example of a phenomenon that is not homogenous with time which makes replication impossible. Recognising this, Checkland suggests that Action Research projects should instead aim for ‘recoverability’. This involves pre-defining the area of the social activity that is to be studied, the theoretical framework and the methodology that will be used to investigate the area of interest. In doing so, the aim is to allow the reader of the resultant research report to ‘recover the process’ that was undertaken and the key decisions that were made and so be able to evaluate validity of that process and the resultant findings.

This theme of making the research process transparent and explicit is continued by other Action Research scholars who suggest other strategies for improving this aspect of the approach. For example, McNiff and Whitehead (2006) recommend declaring the researcher’s pre-knowledge and possible bias relating to the area being studied. This might involve detailing their previous employment history, any political affiliations or significant life events that might influence their interpretation of the situations they encounter. The same authors also recommend using a research review panel consisting of researchers or experts independent of the project to critically examine the findings being generated at various stages of the project. By using these types of strategy it is possible for researchers to engage in the Action Research process whilst still maintaining sufficient levels of rigour to allow for the generation of valid and useful findings.

Action Research has only rarely been used as a methodology within engineering design research (e.g. Bhamra et al., 1999, Björk and Ottosson, 2007, Ottosson, 1996), however the characteristics of Action Research make it particularly appropriate for the study of product development and design activities (Ottosson and Björk, 2004). Ottoson and Björk suggest that ‘Participatory Action Research’ (PAR) – which they distinguish from other forms of Action Research by the amount of time the researcher spends within the research setting (over 80% of project time), and by the participation of the researcher within the design activity being investigated (e.g. as a designer or as a Project Manager) – is relevant for design research because it is only by being within the research setting on an almost continuous basis that the researcher is able to ensure that they witness the small but critical events that lead to significant developments at a later stage (Ottosson and Björk, 2004).

Some of the advantages of adopting an Action Research methodology when investigating the introduction of eco-innovation tools would be:

- *Suitability for studying industrial practice* – because one of the aims of Action Research is to contribute to professional practice, and indeed to be conducted by practitioners, it is well suited to studying industrial practice.
- *Supports active intervention within a research setting* – unlike a case study or design experiment approach, Action Research is based around a principle of the researcher actively intervening within a research setting.
- *Participatory nature* – this is claimed to promote greater interaction, communication and empathy a between the researcher and the participants (Ottosson, 1996). This will be vital for understanding the real needs of designers and so avoid the tools developed being left on the shelf
- *Participants as co-inquirers* - Action Research promotes the view that the research participants should become 'co-inquirers' within a study, helping to make key decisions about the direction of the research. This collaborative approach should help to develop 'buy-in' to the research from designers and design managers which is considered to be important for the successful adoption of DfE tools (Ritzén and Lindahl, 2001).
- *Cyclical nature of the research process* - Action Research cycles will facilitate the iterative development of a design tool within a compressed time frame. This will be useful as in attempting to provide tools for this relatively new topic, it is unlikely that they will be 'right first time'.

Some of the disadvantages of adopting an Action Research methodology when testing eco-innovation tools would be:

- *Concerns over validity and generalisability* – as with case studies, concerns have been raised about the validity of Action Research as a methodology and the generalisability of the findings derived from such approaches. This criticism can be avoided by clearly stating the limitations of the findings and by employing some of the strategies discussed previously to reduce the risk of bias e.g. making the research approach and analysis as transparent as possible.
- *Conflicts arising from moral and ethical issues* – as Action Research encourages the research to practice in a way that is in keeping with their values, conflicts may occur between the requirements of the research and the requirements of participating companies trying to engage in eco-innovation e.g. can the researcher avoid using useful findings from a previous case in later cases in order to maintain their theoretical 'purity'?
- *Lack of familiarity with the methodology within the engineering design research community* – Action Research is not commonly used within the engineering design

research community and hence it may be more difficult for the community to evaluate the quality of the work and accept the research findings.

3.2.5 Selection of the research approach

Having reviewed four different possible research methodologies in the previous sub-sections, this sub-section explains the choice of the research methodology.

A summary of the advantages and disadvantages of the four research methodologies reviewed is presented in Table 3.1.

Methodology	Advantages	Disadvantages
Design Experiments	• Improved claim to 'internal' or 'construct' validity • Repeatability • Acceptability of results within the research community	• Risk of Hawthorne effect • Theory-testing not theory-building • Difficulty in investigating contextual factors • Reductionism not appropriate
DRM	• Relevance for design research • Acceptability of results within the research community • Focus on improved practice • Flexible approach	• Quantitative measures are not always useful • Quantitative measures formulated too early in the research process • Focus on quantitative measures can draw attention away from important issues • Lack of experimental control not accounted for
Case studies	• Suitability for studying industrial practice • Well-developed strategies for improving the rigour and validity of findings • Well-defined process for theory generation • Ability to deal with both qualitative and quantitative data	• Concerns over validity and generalisability • Lack of familiarity with the methodology within the engineering design research community
Action Research	• Suitability for studying industrial practice • Supports active intervention within a research setting • Participatory nature • Participants as co-inquirers • Cyclical nature of the research process	• Concerns over validity and generalisability • Conflicts arising from moral and ethical issues • Lack of familiarity with the methodology within the engineering design research community

Table 3.1: Summary of the advantages and disadvantages of various methodologies

The primary consideration in selecting a methodology is whether or not it will help to design, execute and analyse research that will produce significant and interesting research findings given the particular problem of interest. In this case, the problem of interest is why companies are not adopting eco-innovation tools into their organizational practices. Referring back to the model of this issue based on the realism perspective, there is a need to understand both the *mechanism* by which tools become adopted into industrial practice and the *context.* It was previously noted that design experiments will not be helpful in investigating some of the contextual factors surrounding tool introduction and adoption as they ignore the subjective motivations of actors within the research setting. Furthermore, design experiments are more relevant for theory testing rather than theory building. As the development of eco-innovation tools and their adoption into the organisational practices is a relatively new area of research, there is very little existing theory to test and hence the work will focus on theory building. For these key reasons design experiments were deemed to be inappropriate for the current research.

Considering next the DRM methodology, this was also deemed not to be an appropriate methodology because of the fact that it requires very specific outcome metrics to be defined during the early stages of the research. This was not considered to be possible because of the lack of theory available concerning the development, introduction and adoption of eco-innovation tools available to inform the development of such metrics. Also, it was felt that by focusing on pre-defined outcome metrics there was a risk of missing other emergent issues or impacts stemming from the research intervention.

Case study methodology was considered to be a potentially useful approach because of its suitability for studying industrial practice. Whilst implications for industrial practice can often be drawn from design experiments, it was felt that in order to study the industrial adoption of eco-innovation tools it was an imperative that the research be industrially based. Furthermore, it was felt that the greatest learning would occur by working with more than one company. Case study methodology therefore provided a highly relevant framework within which to study industrial practice across multiple organisations. Also, it was noted that the methodological support for the process for theory building from case study research described by Eisenhardt would be very useful given that the research aimed to generate new theory on the development, introduction and adoption of eco-innovation tools. For these reasons, case study methodology was chosen as the foundation for the methodology used within this research.

However, there was a significant methodological problem in that case study methodology normally involves studying a ‘naturally’ occurring phenomenon i.e. examples of the problem or phenomenon are found and then studied. Unfortunately, the researcher was not aware of any examples of companies trying to, or having previously attempted to, develop or introduce eco-innovation tools at the time of the research. One option would have been to have studied companies that had or were planning to introduce eco-design tools as there were many notable examples of such companies. However it was decided that this would be unsatisfactory due to the significant differences between eco-design and eco-innovation tools which could limit the generalisations that could be made between the two types of tool.

Instead, it was decided to create a range of eco-innovation tools that could then be introduced to companies in order to study how the tools could be customised, introduced and possibly adopted into the organisational practices. This approach represented a fundamentally different approach to conventional case studies. For this reason it was decided that the methodology should also draw on features of Action Research as this approach provides a theoretical foundation for research activities that actively intervene within an organisation. Furthermore, the cyclical nature of Action Research inquiries was deemed to be a useful trait as it would encourage rapid iterations of tool development.

It was therefore decided to use a combination of case study methodology and Action Research in order to support the intervention-based, industrially-located research activities that were necessary to study the research problem.

3.3 Research questions

In Section 1.4.1 the research aim was defined as follows:

> *This research aims to understand how eco-innovation tools can be developed and introduced to a company such that they are adopted into the long-term practices of the company and contribute to the development of eco-innovative products.*

In Chapter 2 a review of the literature on eco-innovation, the management of radical innovation, change management and the introduction of eco-design tools lead to the conclusion that tool customisation was a promising approach to encouraging the adoption of eco-innovation tools within organisations. This led to the definition of the following research questions which were used to inform the design of the research activities:

1. *Which innovation tools, if any, are potentially suitable for eco-innovation?* – it had been decided to use existing innovation tools as the basis for creating the innovation tools to be studied but it was not clear which tools would be most suitable. This question was therefore aimed at identifying existing innovation tools that might be relevant for eco-innovation.

2. *What are companies’ initial responses to eco-innovation tools?* – given that the research activity would involve introducing eco-innovation tools to companies it was felt that understanding their initial reactions might help understand how or why companies prefer certain eco-innovation tool over others.

3. *Can innovation tools be customised to the eco-innovation requirements of a company?* – tool customisation had been highlighted as being a potentially useful strategy for encouraging the adoption of eco-innovation tools within an organisation. As this strategy had never been attempted previously it was necessary to establish if it was possible.
4. *If so, how?* – if tool customisation was possible it was important to try and identify the successful tool customisation strategies such that they might be formulated into a generic tool customisation process.
5. *What are the drivers and barriers to the long-term adoption of eco-innovation tools?* – change-management theory would suggest that the introduction of new ways of working, such as the use of eco-innovation tools, would meet resistance from within the organisation. It was therefore important to identify what types of resistance might be encountered by the companies attempting to introduce eco-innovation tools and to identify strategies for overcoming those barriers.

3.4 Overview of research activities

This section: provides a brief overview of the research activities completed; shows how the research questions were related to the research activities (Table 3.2); describes how the case-study companies were selected and recruited; and describes the research timeline. A full description of each of the activities is provided in the relevant sections.

3.4.1 Preliminary study

A full description of the preliminary study and the findings from that study are presented in Chapter 4.

The aim of the preliminary study was to gain a better understanding of how companies were responding to drivers for ECD. To explore this, benchmarking activities were developed to investigate how companies innovate, develop new products and manage the environmental aspects and impacts of their activities. The benchmarking activities were applied within six companies who shared the characteristics of: having in-house design teams with significant influence over the design of the product; and manufacturing products that were within the scope of environmental legislation such as the WEEE, Restriction of Hazardous Substances (RoHS) (European Commission, 2003a) or Energy-using Products (EuP) (European Commission, 2005) Directives.

3.4.2 Development and in-house testing of the eco-innovation tools

A full description of the development of the eco-innovation tools, the in-house testing of the tools and the conclusions from that study are presented in Chapter 5.

A review of innovation tools searched for tools that can be applied during the very early stages of the innovation process and can help to develop problem definitions at higher systems levels. Ten tools were identified from this search as possibly being relevant for eco-innovation activities. These tools were then adapted for eco-innovation activities by first highlighting the apparent limitations from an eco-innovation perspective before making changes to try and resolve these issues. In-house testing of the tools was completed over a series of workshops with academic colleagues. A combination of the feedback from the participants, the outcomes from the workshop and the researchers observations were used to evaluate the tools in terms of their potential for eco-innovation. From this evaluation, five tools were selected for the industry trials.

3.4.3 One-day workshops

A full description of the protocol for the one-day workshops and the conclusions from that study are presented in Section 6.2.

The five eco-innovation tools that had previously been selected were introduced to six companies (one of these companies had participated in the preliminary study, the others were new to the research) through a one-day workshop in each of the companies. The workshops were held within the offices of the companies and were attended by representatives from engineering, manufacturing, marketing and environmental management functions. For each tool the team were given an introduction to the tool and guided through a worked example. They were then set a task to complete within around 1 hour. The teams completed a tool feedback form after each tool and were asked to rank the tools in order of preference at the end of the workshop. Audio recordings of the feedback sessions were taken and later transcribed and coded (the coding scheme development and evaluation is described later in this chapter).

3.4.4 Two-week tool introduction study

A full description of the protocol for the two-week tool introduction study and the conclusions from that study are presented in Sections 6.3 – 6.7.

Two-week tool introduction studies were completed with four of the six companies that had completed the one-day workshops. The aim of the studies was to introduce one or two of the eco-innovation tools to the companies, to customise the tools based on feedback from the design team and then to reapply the tools to some real company projects. As well as evaluating the success of the tools and the customisations made, it was also decided to investigate the drivers and barriers to the long-term adoption of the tools within each of the companies. This latter objective was investigated using interviews with design team members and managers, the audio recording of which was transcribed and coded.

3.4.5 Round-up seminar

In January 2009 all of the companies that had participated in the research were invited to attend a round-up seminar. The aims of the seminar were:

- to feedback the researcher's initial findings and conclusions;
- to learn more about the companies' experiences of participating in the research and what developments there had been since the end of the tool introduction studies;
- to encourage networking amongst the companies.

During the seminar two of the case-study companies gave presentations about their experience of participating in the research; one of the case study companies presented some details of their eco-design process; Environ UK Ltd. discussed the benefits of voluntary approaches to legislative compliance; and the researcher presented initial findings and conclusions from the research. Towards the end of the seminar a generic model for the introduction of eco-innovation activities within a company was presented to the companies for discussion. This model is presented within this thesis in Chapter 7.

Table 3.2 shows how the research questions relate to the research activities completed.

Research question	Research activity					
	Literature review	In-house trials	Benchmarking activities	One-day workshops	Tool introduction studies	Drivers and barriers interviews
1. Which innovation tools, if any, are potentially suitable for eco-innovation?	Chptr 2	Chptr 4				
2. What are companies' initial responses to eco-innovation tools?				Chptr 6		
3. Can innovation tools be customised to the eco-innovation requirements of a company?			Chptr 6		Chptr 6	
4. If so, how?					Chptr 6	
5. What are the drivers and barriers to the uptake of eco-innovation tools?						Chptr 7

Table 3.2: Summary of how the research questions relate to the research activities

3.4.6 Selection and recruitment of case study companies

Having established that the research would be conducted within an industrial setting using a case-study methodology, it was necessary to: determine a 'population' to study; establish a method for sampling that population; and to recruit appropriate companies.

The population to be studied was chosen as producers of Electrical and Electronic Equipment (EEE). The reason for this choice was that EEE producers are facing significant legislative pressures to improve the environmental performance of their products (Section 1.3). This legislative pressure was considered to be a good indication that EEE has a significant environmental impact as it has been prioritised for action, particularly within the EU. It was also believed that one of the consequences of the legislative pressure was that EEE producers would be more likely to be ready to engage in eco-innovation activities. This raised the likelihood of finding a sufficient number of cases within a given population to be able to identify significant themes. Another important influence in the selection of EEE producers as the target population was that this was the main market for the environmental consultancy services of the industrial sponsor of the research.

One significant restriction of the scope of the research was to exclude companies that did not have control over the design of the products that they manufacture. For example, EEE manufacturing sub-contractors could be considered to be 'EEE producers' but it would not have been possible for them to engage in eco-innovation as they would not have had the authority to change the design of the product. For practical reasons, the population was further limited to companies that had design offices with the EU and that used English as the primary business language.

The sampling of a population within an experimental approach normally involves a strategy to ensure a random, unbiased sample. In contrast, in case study methodology 'theoretical sampling' is often used in which cases are carefully selected based on theoretical reasoning rather than for statistical reasons (Glaser and Strauss, 1967). According to Eisenhardt (2002 pp.13), 'the goal of theoretical sampling is to choose cases which are likely to replicate or extend the emergent theory.' In this case, the emergent theory had included a theory that there would be differences in the requirements of eco-innovation described by companies according to their current level of innovation and environmental performance. Figure 3.5 presents this diagrammatically and shows the *initial* placement of the companies within the matrix which was based on a brief review of the companies' websites and their general reputation. The diagram shows that an attempt was made to sample companies from each of the four quadrants of the diagram in order to capture all extremes of company types. Later in the study, it was concluded that the comparative analysis of companies was not aided by this separation according to

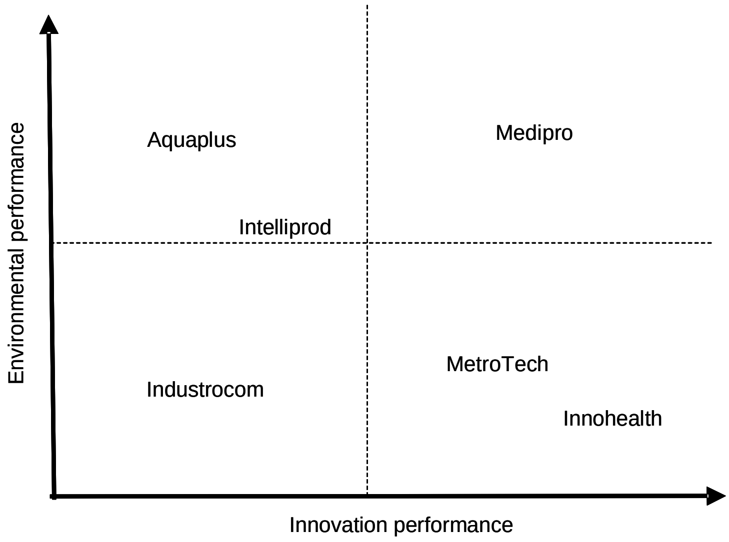

Figure 3.5: Theoretical framework used to guide case sampling strategy

environmental and innovation performance. Nonetheless, this postulate was used as the guiding framework for the sampling of companies.

The companies were recruited into the research in a variety of different ways. The six companies that participated in the preliminary study (which included one company that went on to participate in the main study) were 'cold called' by a research assistant. The companies were offered a presentation on the WEEE, RoHS and EuP Directives in return for their time. The characteristics of the companies that participated in the preliminary study are summarised in Table 3.3.

Company	Size	Product type
I	Medium	Professional audio equipment
II	Medium-Large	Location/inspection equipment, sensors
III	Medium	Water/central heating controls, utilities metering
IV	Medium	Heating, ventilation and hot water systems
V	Medium	Vending machines
VI	Small	Industrial testing equipment

Table 3.3: Characteristics of the participating companies from the preliminary industrial study

For the main study, companies were recruited by: networking at conferences; presenting at sustainability-related trade shows; advertising within trade magazines; and cold calling. The characteristics of the companies that participated in the main study are summarised in Table 3.4.

Company pseudonym	Size	Description
'MetroTech'	Medium	Design and manufacture low-volume, high-value industrial products
'Medipro'	Large	Design and manufacture complex, very high value healthcare products
'Intelliprod'	Medium	Design high-volume, medium-value consumer products
'Industrocom'	Medium	Design and manufacture high-value products for location and inspection (Company II from preliminary industrial study).
'Innohealth'	Small	Began life as an innovation hub to a large corporation, now focused on the design of high value healthcare products
'Aquaplus'	Medium	Design and manufacture of showers.

Table 3.4: Characteristics of the participating companies from the main study

3.4.7 Research timeline

Research reports are generally presented in a way that attempts to neatly and succinctly express the logical development of an argument. This approach has been reinforced by the conventions of scientific journal papers which often contain the headings: Introduction, Methodology, Results, Discussion & Conclusions, or some slight variation thereof. The presentation of research reports in this format is useful as the consistency of presentation leads to familiarity for the reader allowing them to more easily follow the development of the argumentation and to quickly locate the information they are interested in.

The problem with presenting a research report in this neat, linear fashion is that it can imply to the reader that the research process as was actually experienced was also neat and linear. Within the current research, the actual research process was experienced as being rather more 'messy', with the boundaries between different phases of the research, and between the different cases often blurred, and at times chaotic. Hence Figure 3.6 is included here to describe the project timeline and to offer the reader some insight into the research process as it actually occurred. This is particularly important given the participative role of the researcher within the project, a topic discussed further in the next section. As the research progressed, in a chronological sense, the researcher was learning from his experiences. Whilst the methodological aim was to 'repeat' the intervention process in each of the case-study companies in as consistent a manner as possible, it was inevitable that during the later case studies some of the learning from the earlier case studies would 'leak out' (P. W. Reason, personal communication, 8th May 2008).

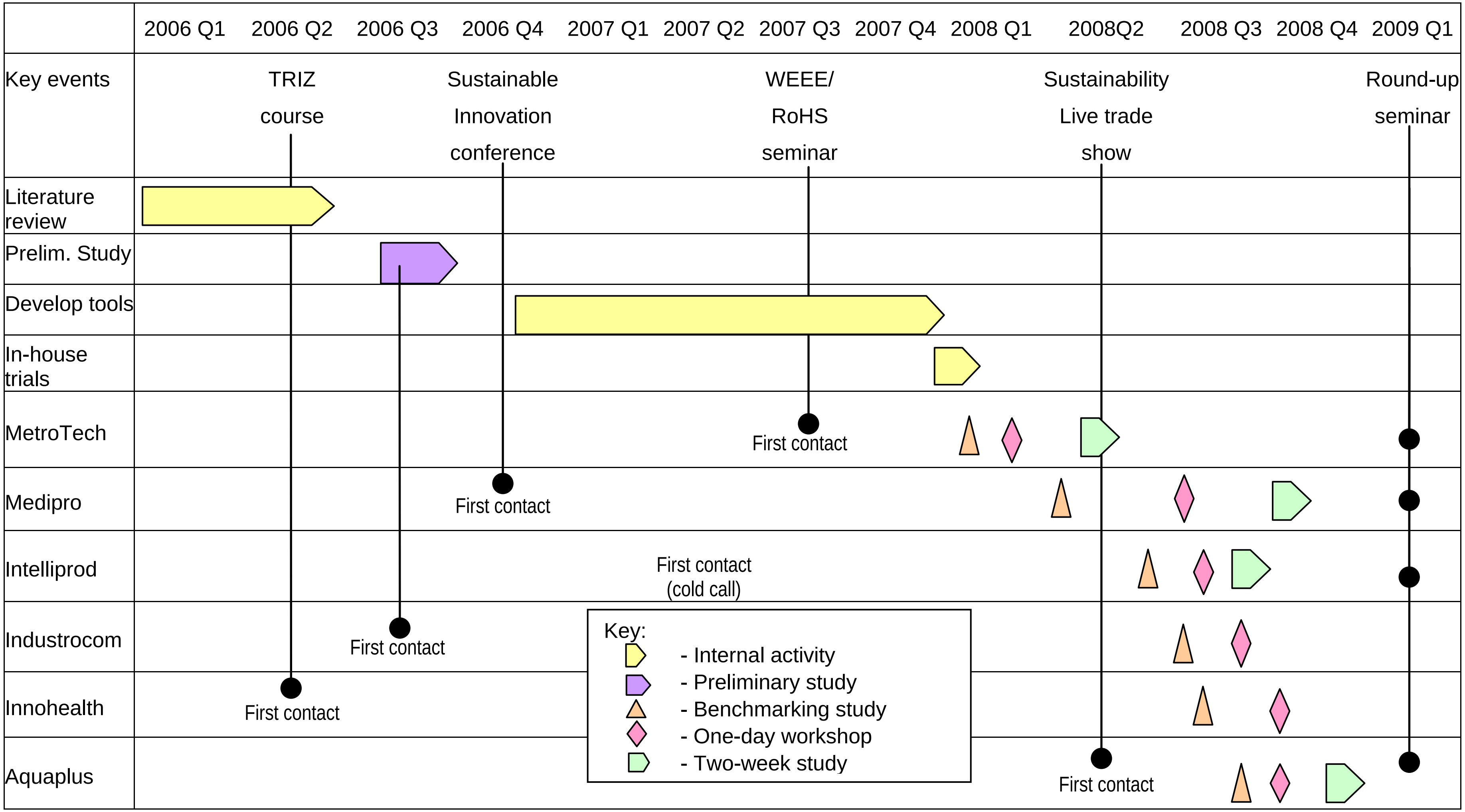

Figure 3.6: Timeline of the research activities

3.5 Data collection activities and issues

Details of each of the main research activities are provided in the relevant sections but in this section some of the general issues associated with the research methods employed are discussed.

3.5.1 The role of the researcher

It was noted in Section 2.2.4 that within Action Research projects extra effort must be made to ensure that the research process is transparent to the reader. This includes clarifying the role of the researcher within the research activities. This is particularly important within this research because the researcher was actively involved in instigating change within the companies studied (through the introduction of the eco-innovation tools).

The nearest formal definition for the role adopted by the researcher within the current research is that of ‘interrupted involvement’ which involves the researcher:

> *Being present sporadically over a period of time, moving, for example, in and out of the organisation to deal with other work or to conduct interviews with, or observations of, different people across a number of different organisations. (Easterby-Smith et al., 2004)*

However, this does not express the fact that the researcher was also actively engaged in instigating change within the case study companies by introducing the eco-innovation tools.

In all case study companies the researcher was presented to the organisation as an academic researcher. However, in most cases the presence of the researcher was only announced to the particular staff that had some formal involvement in the research. The researcher led all the workshops and conducted all the interviews. It was also made clear to the research participants that the work formed part of a PhD project. The possible researcher effects associated with the role played by the researcher are discussed in the following sub-section.

3.5.2 Researcher effects

There are two main sources of bias relating to ‘researcher effects’ that can occur during fieldwork: (A) the effects of the researcher on the case, and (B) the effects of the case on the researcher. ‘Bias A occurs when the researcher threatens or disrupts ongoing social and institutional relationships.’ (Miles and Huberman, 1984, p.265). Bias B is more likely when the researcher spends a considerable length of time within the research setting and risks ‘…being co-opted, going native, swallowing the agreed-upon or taken-for-granted version of local events' (Miles and Huberman, 1984, p.265). In this case, the researcher spent up to two weeks in any one company. Whilst both type A and type B researcher effects are plausible in this type of timescale, on balance, the type A impacts were considered to be a greater risk due to the high profile of the research within the companies (i.e. 'special' sessions being organized by the researcher) and the prominent role of the researcher within the research (i.e. key role in delivering the training and facilitating workshop sessions). Some of the measures proposed to reduce type A and type B bias cited by Miles and Huberman (1984, p.266) and the corresponding measures taken to reduce those biases are shown in Table 3.5 and 3.6:

Suggested measure (Miles and Huberman, 1984)	**Implementation within the research**
'Stay as long on-site as possible; spend some time simply hanging around, fitting in to the landscape, taking a lower profile.'	• Worked the 'normal' office hours of the research location where practical. • Sat in office next to designers when not conducting workshops or interviews.
'Make sure your intentions are unequivocal for informants; why you are there, what you are studying, how you will be collecting information, what you will do with it.'	• Researcher introduced himself and gave details of the aim of the research at the beginning of workshop sessions. • E-mailed an introduction to the research to interviewees.

Table 3.5: Measures to avoid type A biases stemming from researcher effects on the site

Suggested measure (Miles and Huberman, 1984)	**Implementation within the research**
'Avoid the "elite" bias by spreading out your informants; include lower-status informants and people outside the focus of you study.'	• Informants included people not directly involved in the evaluation of the tools and support staff.
'Be sure to include dissidents, cranks, deviants, marginals, isolates – people with different points of view from the mainstream, people less committed to tranquillity and equilibrium in the setting.'	• Deliberately sampled workshop participants who were most critical of the tools or environmental issues for follow-up interviews.
'Triangulate with several data collection methods; don't rely overly on talk, or on observation, to make sense of the setting.'	• Triangulation of informants and measures was completed – how triangulation was achieved is discussed in detail in the following section.

Table 3.6: Measures to avoid type B biases stemming from researcher effects on the site

During the later stages of data analysis a concern was raised that the researcher had been 'co-opted' into the beliefs of certain key informants. For example, a lot of time was spent with the research coordinator within each company. These people were obviously advocates of eco-innovation and so had their own bias. The research coordinators would often also discuss more general issues and problems the company was facing, but again these views only represented one person's opinion. Therefore to avoid these views biasing the researcher, care was taken to review the sources of evidence supporting each of the findings and check that they were not being overly influenced by the views of the research coordinator. This review process led to the omission of several of the initial findings from this thesis.

3.5.3 Interviews

Interviews were held with participants for various reasons during the two-week tool introduction trials e.g. to gather feedback about the eco-innovation tools, to find out about the company's environmental culture etc. Semi-structured interviews were used in all cases as there were specific issues that the researcher wanted to discuss but it was important to have the flexibility to follow-up on interesting comments that might lead to new insights. Although it is often beneficial to use two interviewers – one to ask the questions and one to make notes and observations and act as a cross-check during analysis – this was not possible due to resource limitations and the flexible way in which interviews were arranged during the periods spent with the companies. An audio recording was made of all interviews with permission obtained from every participant prior to the start of the interview. Interview templates were generated prior to an interview which included an introduction to the purpose of the interview (and the research if the participant was not already familiar with the research). Contrary to conventional approaches, some questions were not worded so as to present questions in a neutral fashion i.e. 'To what extent does this tool meet the requirement of being "Time efficient"?', rather than 'To what extent does this tool meet *or not meet* the requirement of being "Time efficient"?'. The decision to word questions in this positively-biased manner was taken because the participants were already very aware of the aim of the research and hence attempts to try and mask the researcher's aims for the research were pointless. Furthermore, by deliberately introducing this type of contrived phrasing of questions to make them neutral may actually have had a bigger impact on the participants' responses by making the questions seem strange or annoying, this point is discussed further in the next sub-section.

At the end of each interview a question was included to allow the participant to mention anything else that they felt was relevant to the researcher's understanding of the issues being discussed that had not been previously mentioned. This tactic helps to increase confidence that no significant issues have been overlooked (Kvale, 1983).

3.5.4 Workshops

When a researcher is present within a workshop his or her simple presence is likely to affect the other workshop participants in some way. One possible strategy to overcome this would be for the researcher to remain very passive – never contributing to discussions, not commenting on ideas etc. However, this in itself could have a significant impact on the group as they may find this strange or annoying. Holme and Slovang (1997 cited in Janhager, 2005) therefore recommend that the researcher acts as the group would expect – although obviously this will be challenging to judge what is 'normal' behaviour. This advice was followed by the researcher during all workshop sessions.

Immediately following workshops the researcher would write a short summary of the workshop describing the basic details of who attended and what activities where completed, any problems encountered, how successful the activities were and any other salient points. The aim of completing such reports was, in the words of Miles and Huberman (1984 pp. 52), 'to pull together the data in the "soft computer" – the field worker's mind'.

3.5.5 Benchmarking activities

The benchmarking activities were used to find out more about the companies' innovation and environmental practices, performance and culture. As a research method, the benchmarking activities shared similarities with both interviews and workshops in the sense that they were being used to find out more about the company and the respondents' experience of the company (like an interview) but also involved some form of activity (such as place the company on an 'Innovator-Adaptor' scale), and often involved several people in one session (like a workshop).

To reduce the likelihood of biased responses within the benchmarking activities the following strategies were adopted:

- Consensus responses – in several of the activities several participants were involved in the activity but they could only provide one response to a question. This forced the participants to discuss their opinions and defend them where there were competing views.
- Asking for evidence – During activities such as the innovation culture questionnaire, when participants claimed that, for example, they strongly agree with the statement 'The management provide support for design, creativity and innovation', the researcher would ask the participant to provide some evidence to support this view.

3.6 Data processing and analysis

The term ‘data processing’ is used here to describe the processes involved in taking raw data and transforming them into a format which is convenient for data analysis. Data processing and analysis are in theory distinct activities but will be discussed together in this section as in practice it was found that there was significant overlap.

The data processing and analysis for this research was completed in two phases. The first phase was immediately after the completion of each of the main case studies. The output of this analysis was a short report containing a summary of the activities completed, the outcomes and the recommendations for further action for the company. These reports were company confidential and have therefore not been included within this thesis.

The second phase was a more in-depth analysis which involved transcribing a significant amount of the audio data collected. These data were subsequently analysed using a Grounded Theory-style approach (described in Section 3.6.3) which involved coding the transcripts against a coding scheme and the application of analytical strategies.

The first half of this section describes the data processing and some of the lower-level data analysis activities including the development and testing of the coding scheme. The second half of the section describes the strategies used in the higher-level data analysis.

3.6.1 Selection of data sources to transcribe and analyse

Due to the large quantity of audio data recorded (30+ hours of interview data and a similar amount of workshop data) a strategy was required to reduce the data processing and analysis to a manageable amount. The aims of this strategy were:

- to ensure that similar types of sources were analysed from each of the cases; and,
- to focus on key events and sources that were considered most likely to offer the most insightful or disconfirmatory evidence (the latter being part of the ‘falsification’ strategy (Popper, 1959) described in Section 2.6.6).

Table 3.7 provides an overview of the number of audio sources recorded, and of those, the number transcribed and coded. The process used to select the sources was as follows:

1. The sources were grouped by type e.g. ‘Week 1 tool individual feedback interviews’ or ‘Drivers for environmental performance interviews’ (see the first column of Table 3.7).
2. All of the one-day workshop group feedback sessions and the Week 2 group tool feedback sessions were chosen as these were considered to be key events.

3. Of the remaining sources, at least one example from each of these categories within each company was chosen. Where there were multiple sources to choose from, the choice of source to analyse was made by the researcher based on a brief review of the interview notes and consideration of the interviewee. Sources that contained particularly noteworthy comments or key remarks were given precedence over more 'run of the mill' sources. Sources were also selected if the interviewee was considered to hold more negative or sceptical views concerning the benefit of the eco-innovation tools.

It was decided not to transcribe the workshop sessions, other than the sections of tool feedback, as for the majority of the time, the participants were focused on the task they were completing and were not commenting on the quality or value of the tool. Furthermore, the outcomes from the session were captured in the worksheets, which were photographed and reviewed separately.

Source type	**Case**					
	MetroTech	Medipro	Intelliprod	Industrocom	Innohealth	Aquaplus
One-day workshop group tool feedback	●●●●●	●●●●	●●●●●	●●●●●	●●●●●	●●●●●
Week 1 ind. tool feedback interviews	●●●	●● ○	●●● ○○	X	X	●●●● ○○○
Week 2 group tool feedback	●●●	●●	●●●	X	X	●●●
Tool introduction interviews	●	● ○	●	X	X	● ○
Drivers and barriers for eco-innovation interviews	●	● ○	●●● ○	X	X	● ○
Total minutes of audio transcribed and analysed	315	280	319	-	-	319

Key: ● – Source transcribed and coded.

○ – Source recorded but not transcribed or coded.

Table 3.7: Overview of the audio data sources selected for transcription and analysis.

Although the number of interviews and the amount of audio data varied quite significantly from case to case, it was decided that a similar amount of data in terms of minutes of audio recording should be analysed from each case to help ensure a fair comparison when conducting inter-case analysis. Table 3.7 shows that the total amount of audio data transcribed and analysed per case ranged from 280 to 319 minutes.

The interview data was transcribed using a professional transcription service. The first transcripts received from the company were checked in detail by the researcher by listening back to the original audio recording whilst reading the transcript. The workshop tool feedback sessions were transcribed by the researcher as the conversations within these sources were harder to follow and transcribe without very being familiar with the participants' voices.

3.6.2 Use of qualitative data analysis software

The Qualitative Data Analysis Software (QDAS) package NVivo8 was used to support the processing and analysis of the transcribed data. For the current research, the beneficial features of QDAS compared to 'manual' methods included:

- Keyword searches - useful for finding references to a particular case, product or event etc.
- Powerful, compound, Boolean logic search capability – useful for identifying key themes within the data.
- Automated processing of inter-coder reliability tests – saves time compared to performing these tests manually.
- Ability to hyperlink memos to sources – useful for reflecting on the data and subsequent theory-building.

These types of capability were considered to be potentially very useful in supporting a Grounded Theory-type analysis and therefore it was decided to employ QDAS within the analysis activities.

3.6.3 Development and use of the coding scheme

In this research a coding scheme was developed to try to codify the discourse of participants into more generalised themes such that similar themes from across the range of participants and cases could be identified and grouped together. The ultimate aim of using this coding scheme was to allow the researcher to:

- highlight instances of a theme across multiple sources and cases – which in turn facilitates the ability to;
- identify significant themes; and,
- provide direct evidence in support of conclusions and an 'audit trail' back to primary data thus rendering the analysis more transparent and, it is hoped, more convincing.

‘Codes’ have been described as:

> *Tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study. Codes are usually attached to ‘chunks’ of varying size – words, phrases, sentences or whole paragraphs, connected or unconnected to a specific setting. They can take the form of a straight-forward category label or a more complex one (e.g. a metaphor). (Miles and Huberman, 1984)*

But where do these ‘codes’ come from? There are two main alternative approaches to the creation of codes and the ‘coding scheme’. Glazer and Strauss originally recommended that codes should emerge from the data and that the researcher should hold no preconceived ideas as to what the codes should be (Glaser and Strauss, 1967). This activity was what they referred to as ‘open coding’. The alternative view is that the researcher should define *a priori* a set of codes which are then modified or added to as the analysis progresses. This is the approach advocated by scholars such as King in his description of ‘Template Analysis’ (King, 1998). For this research a set of *a priori* codes were defined because the researcher had read a significant amount of theory on the topic being studied (and therefore already had what might be called a ‘cognitive coding scheme’), and because some initial analysis had already been completed in the compilation of the company feedback reports. Hence, it was not possible to begin developing a coding scheme with the ‘blank slate’ required for the original Glazer and Strauss approach.

The coding scheme was therefore developed in a similar, but not identical, manner to that recommended for template analysis by completing the following steps:

- *Code generation* - Separate lists of possible codes were created based on:
    - Existing literature - key themes from the literature on tool introduction and the drivers and barriers for ECD activities were included to help strengthen, or perhaps disprove, previous explanations;
    - Research questions – this was essential to ensure that sufficient evidence was gathered concerning the main topics being researched.
    - Review of the company feedback reports – the initial feedback reports had identified some key themes and issues within each of the case study companies but were based on initial impressions and field notes rather than detailed analysis. It was therefore necessary to re-examine these themes using a more rigorous approach to strengthen or disprove these insights.

- *Code consolidation* - The three lists were compared and merged to consolidate similar codes. The codes were structured in a hierarchical form with 'structural codes' added as grouping structures. This was designed to allow multiple levels of coding which would provide opportunities for analysis at multiple levels. From this point onwards, a record was kept of any modifications to the coding scheme. Figure 3.7 provides an overview of the final coding scheme, showing the 11 high-level themes as well as some of the lower-level themes under the 'Tool introduction' code. The full coding scheme can be found in Appendix 2.

- *Coding-scheme pilot* - The coding scheme was applied to a sample of ~5% of the total transcribed material. During this initial coding activity when a comment that seemed relevant to the research questions could not be neatly fitted into the coding scheme, codes were modified or new codes created to accommodate the comment. After the sample was completely coded a review led to the elimination of certain codes that had not been used.

- *Application of the coding scheme* – The coding scheme was applied to all the transcriptions. During this time four modifications were made to the coding scheme. These were: the creation of two major new themes; the deletion of one unused theme; and the creation of two sub-level codes. The relatively small number of changes to the coding scheme suggests that it was sufficiently stable and comprehensive.

It is now strongly recommended by scholars that regularly use Grounded Theory or Content Analysis-type approaches that a review of the coding activity is completed to verify the coding scheme and to assess the quality of the coding activity (Neurendorf, 2002). This is discussed in detail in the following sub-section.

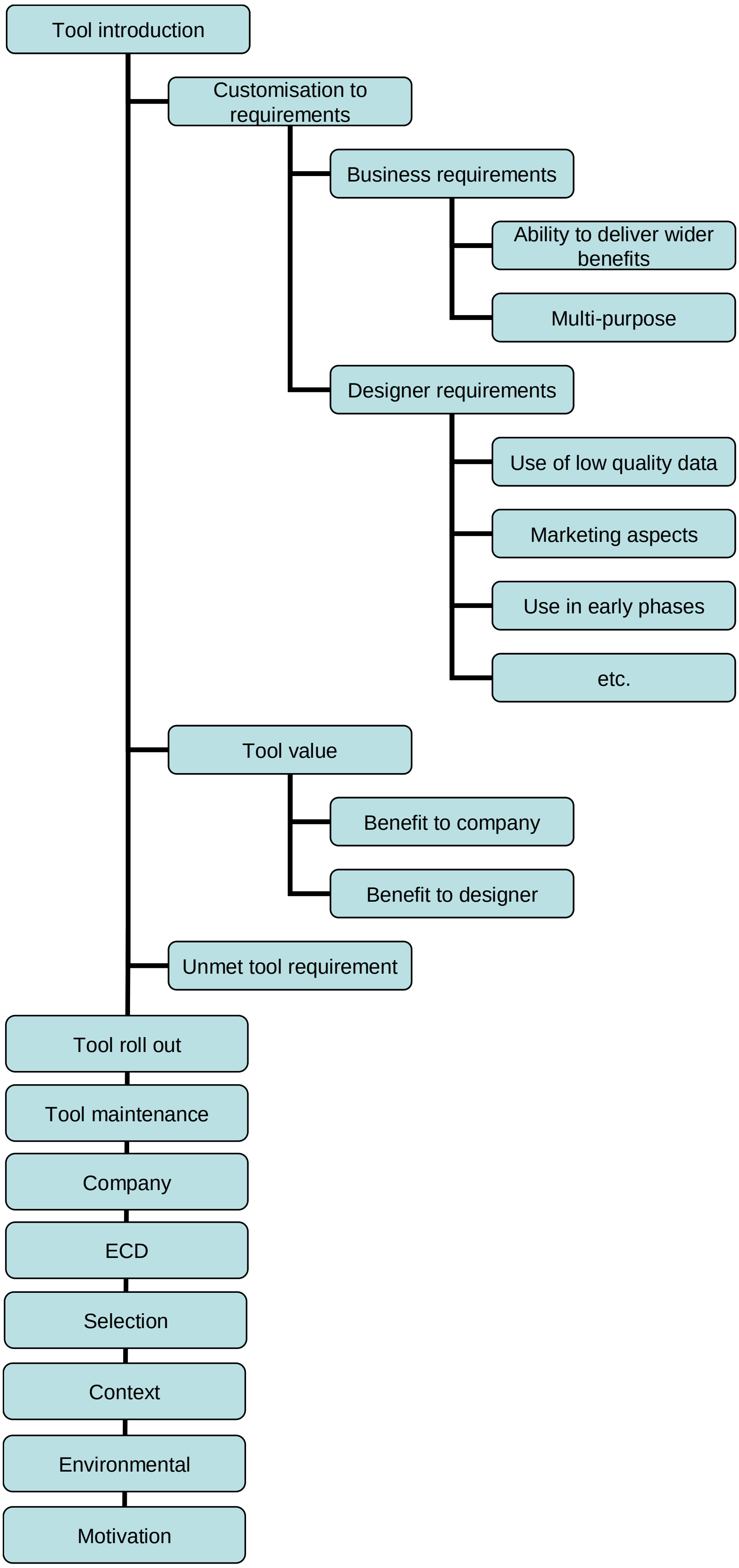

Figure 3.7: Overview of the coding scheme (not all lower level codes shown).

3.6.4 Assessment of the coding scheme

It is now common practice to make some kind of assessment of the coding scheme and the coding activity when undertaking qualitative data analysis, particularly in the field of Content Analysis (Neurendorf, 2002). However, the reader must first be convinced that the coding activity was done in a robust and systematic manner. This can be achieved in a number of ways including checking the acceptability of the coding with some of the participants (e.g. Hardy et al., 2003) or by performing some kind of inter-coder reliability test (e.g. Beadle, 2008). The aim is to prove that a coding scheme is sufficiently detailed and explicit that any two competent people, trained in the use of a particular scheme, should apply the coding scheme to a given set of data in the same way. However, for the current research it was decided that an inter-coder reliability test was not practical or necessary as:

- The results of the coding were not going to be analysed quantitatively using statistical methods as is often the case in Content Analysis-based research
- The coding scheme was of a size and complexity (94 distinct codes) that it would have required an unrealistic amount of effort from a volunteer colleague to learn and apply
- The end result is arguably not evidence of the objectivity of the coding scheme but simply a demonstration of the ability to train someone to follow a convention e.g. coding remains an 'inter-subjective' activity (Potter and Levine-Donnerstein, 1999).
- There was only one researcher performing the coding and hence the problems of trying to use coding data from multiple coders did not exist.

Nonetheless, it was felt that some form of coding check was necessary as if the coding was not completed in a reasonably systematic manner then there was a risk that instances of a theme would be omitted from the subsequent analysis. Hence, instead of an *inter*-coder test, an *intra*-coder reliability test was performed in which the consistency over time of a researcher is assessed (Robson, 2002). This approach was justified by the fact that it was a much more practical measure to implement and yet could still provide good evidence of the consistency of application of the coding scheme.

The intra-coder reliability test was completed on a sample of approximately 10% of the coded material. The material was taken from the corpus of case study data that was transcribed and used in the analysis. It is recommended that at least one week elapses between the original coding of material and the subsequent recoding (Robson, 2002). This was achieved by using a random sample of sources coded during the early stages of the original coding activity at least one month prior.

Percentage agreement was used as the reliability test measure and an agreement level of 85% was set as the target for each of the codes. Of the 455 agreement checks (five sources checked against 91 codes), four codes showed agreement of less than 85%. These were:

- Designer's requirements/Life cycle perspective – 73%
- Designer's requirements/Marketing aspects – 77%
- Designer's requirements/Time requirement – 84%
- Barriers to adoption – 84%

The first three of these results came from one source. The coding was reviewed for each of these cases and the majority of discrepancies were resolved by reflecting on what might have caused the disagreements. It was felt that the discrepancies were not symptomatic of systematic errors or biases in the coding and therefore it was concluded that the coding had been performed to an acceptable standard.

3.6.5 Unit of analysis

The unit of analysis for this research is 'a company' as the aim of the research was to increase the uptake of eco-innovation tools across entire companies. In line with this, data were collected using personnel from across several design teams and several different organisational functions. The choice of a company differs from the work of Lindahl (2005) who focused on the designer as the unit of analysis. It was hoped that this choice of the unit of analysis would compliment the work by Lindahl and others that have focused on the designer by offering a wider view of the 'system' into which the eco-innovation tools were being introduced.

3.6.6 Analytical strategy

On the topic of analytical strategy, Yin (2003) notes that:

> *'The analysis of case study evidence is one of the least developed and most difficult aspects of doing case studies…..Unlike statistical analysis, there are few fixed formulas or cookbook recipes to guide the novice'.*

Therefore to aid analysis a number of particular analytical strategies were employed. These were:

- *The use of questioning* – a number of detailed questions, based around the research questions, were generated when trying to analyse the data. This approach has been recommended for assisting the researcher in overcoming the initial difficulties in knowing where to start with data analysis (Corbin and Strauss, 2008 pp.69).
- *The 'flip-flop' technique* – this technique involves turning concepts 'upside-down' or 'inside-out' in order to gain a different perspective of the concept (Corbin and Strauss, 2008 pp.79). In this case, the concept 'taking action to encourage the adoption of eco-

innovation tools' was flipped to create the idea of 'taking action to prevent the adoption of eco-innovation tools'. This led the author to think of the following actions that might be used to prevent the adoption of an eco-innovation tool, for example:

- Not tell anybody about it
- Argue that there is no business case for eco-innovation
- Argue that it does not add anything that cannot already be achieved using existing methods
- Argue that the results are not accurate/valid or applicable

These ideas were then flipped again and led to the following questions which were used to guide analysis and interrogate the data:

- How was the research communicated within the organisation?
- How convinced were the participants of the need/business case for the tools?
- What benefits did participants find from using the tool?
- Were the participants convinced of the validity of the tool outputs?

- *Falsification* - No matter how much confirmatory evidence is gathered one can never be entirely sure that there is not a case in the world that does not 'fit' with the theory being tested. However, if such anomalous cases are actively sought and not found, then the confidence in the validity of the findings can increase (Popper, 1959). This strategy was enacted within the research in the following ways:
  - Providing opportunities for negative feedback during interviews.
  - Encouraged negative comments during workshops.
  - Identified the most open critics/sceptics of the tools from workshops and made sure to include them within interview samples.
- *Triangulation* - aims to strengthen research findings by using two or more different approaches to the investigation of a research question in order to search for similarities and regularities. Triangulation was enacted within the research study by, for example: repeating the same types of interviews with different participants within a company (triangulation of sources); and using feedback forms which required both quantitative scores and qualitative comments (triangulation of measures).

The use of these analytical strategies therefore enabled deep insights into the data whilst at the same time increasing the validity of the findings by ensuring that the analysis was comprehensive, robust and recoverable. One additional strategy employed to increase confidence in the research findings was the use of validation by the participant companies. This involved sending the company reports and academic papers discussing the findings of the research to the companies for comment. Within the round-up seminar, there were also opportunities for the companies to comment on the initial findings. This combination of analytical strategies and validity cross-checks therefore helped to ensure a solid methodological foundation for the findings discussed in later chapters.

3.7 Summary

This chapter began by discussing the philosophical foundations of the research activity, noting that this would affect the choice of methodology, methods and the formulation of research questions. Realism was found to be the philosophical perspective most appropriate for the research aims and most closely aligned to the researcher's personal views as it assumes the existence of a real external world whilst acknowledging that people within a social setting will act with intent and their own subjective purpose. Following from this, four alternative research methodologies were reviewed with respect to their ability to guide the research and to produce findings that would be interesting and acceptable by the engineering design research community. From this evaluation, a case study methodology was selected as the foundation of the approach. However, it was found necessary to supplement case study methodology with aspects of Action Research given the need to actively intervene within the research setting by introducing eco-innovation tools.

In Section 3.3 the research questions were presented and briefly discussed before an overview of the main research activities was presented in Section 3.4. The latter included a description of how the case-study companies were selected and recruited into the research. Section 3.4 also included a description of the research timeline which was intended to make transparent the chronological development of the research in recognition of the fact that the researcher was learning constantly throughout the process and that this was likely to have influenced the later activities.

Section 3.5 described the data collection methods, specifically interviews, workshops and the benchmarking activities and discussed some of the main issues associated with those including the role of the researcher within the case study companies and researcher effects. Finally, Section 3.6 described how the qualitative data was processed by transcribing and coding and discussed some of the main issues associated with those activities including the selection of sources to analyse, the development, use and validation of the coding scheme. It went on to define the unit of analysis for the research as 'a company' and described how the processed data was subsequently analysed using a number of different analytical strategies.

This chapter has thus briefly described the main research activities conducted and the principal methodological decisions and issues encountered. In subsequent chapters the research methodology for the specific activities are described in more detail and the results of those activities presented and analysed.

N.B. It was not possible to make the raw data collected during the course of this research available to third parties due to confidentiality agreements established between the research institute and the participating companies.

4 Preliminary industrial study

The vast majority of ECD literature that discusses the introduction and use of ECD tools has been based on studies involving DfE or eco-design tools. It was therefore considered necessary to investigate a number of issues that would be pertinent for the development of the eco-innovation tools, such as:

- What types of environmental pressures were companies facing?
- How were the companies responding to legislation and other types of environmental pressure?
- If eco-innovation tools need to integrate with existing innovation and NPD processes, what do those processes look like?

A preliminary industrial study was therefore undertaken to find answers to these questions, by speaking to companies directly and finding out more about their environmental, innovation and NPD activities (O'Hare et al., 2007).

Within this chapter, Section 4.1 describes the development of the benchmarking activities which were used to investigate companies' innovation and environmental performance. Section 4.2 describes the methodology used for the study and Section 4.3 presents the findings. Finally, Section 4.4 provides a summary of this chapter.

4.1 Preliminary industrial study methodology

The study was conducted with six companies that designed and manufactured products in the South-West of England that were likely to be affected by the Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS), or Energy Using Products (EuP) Directives. The companies were 'cold called' by a temporary research assistant. The companies were offered a presentation discussing the implications for manufacturers of the WEEE, RoHS and EuP Directives in return for their time. The characteristics of the companies that participated in the preliminary study are summarised in Table 4.1.

The aim of the study was to gain an understanding of the *real* practices of companies. Previous studies of organisational culture have found that often there are significant differences between what a company says it does and what actually happens (Schein, 2004). It was therefore decided to develop a range of activities which would require the company to demonstrate their environmental and innovation performance by providing evidence and concrete examples. Although the activities offered fairly crude measures of innovation and environmental performance, this was acceptable due to the fact that measuring company performance was not the main focus of the research activity. Rather,

Company	Size	Product type
I	Medium	Professional audio equipment
II	Medium-Large	Location/inspection equipment, sensors
III	Medium	Water/central heating controls, utilities metering
IV	Medium	Heating, ventilation and hot water systems
V	Medium	Vending machines
VI	Small	Industrial testing equipment

Table 4.1: Characteristics of the participating companies

it was to learn more about how the companies were managing environmental requirements within their innovation and NPD activities and where eco-innovation activities might naturally fit into these activities.

4.1.1 Supply-chain pressures activity

The aim of this activity was to understand what types of environmental pressures the company were facing and what pressures they were placing on their suppliers. The balance of these two was considered to offer an indication of how ‘pro-active’ the companies were with respect to the environmental impacts of their supply chain.

The team of company representatives were presented with a large flip-chart sheet divided into two by a line vertically down the middle. It was explained that on one side of the line they should note down the environmental pressures they were receiving from their customers e.g. demands for proof of RoHS Directive compliance, environmental questionnaires etc. On the other side of the line, the team was asked to note down examples of environmental pressures that they were placing on their suppliers. In both cases, the team was asked to provide a reasonable level of detail about the pressures being described.

4.1.2 Life cycle thinking activity

The aim of this activity was to understand what actions had already been taken to improve the environmental impacts of their activities. A chart listing six life cycle phases was presented to the participants. The researcher then went through each life cycle phase asking for examples of actions or initiatives taken by the company to reduce the environmental impacts associated with that phase. A standard, generic list of positive environmental actions was read to the team if clarification was requested.

4.1.3 NPD process mapping

This activity was designed to both capture the NPD process of the company as it was experienced in practice, and to build a critique of that process. The activity was introduced by presenting the participants with examples of both formal and less formal NPD process models and asking which of the examples were most closely related to the company's own process. The participants were then asked to talk through and map out their NPD process on flipchart sheets. This map was further elaborated by asking the participants to add comments to identify general strengths, in green pen, and general weaknesses, in red pen. An example of a completed NPD process mapping worksheet is shown in Figure 4.1.

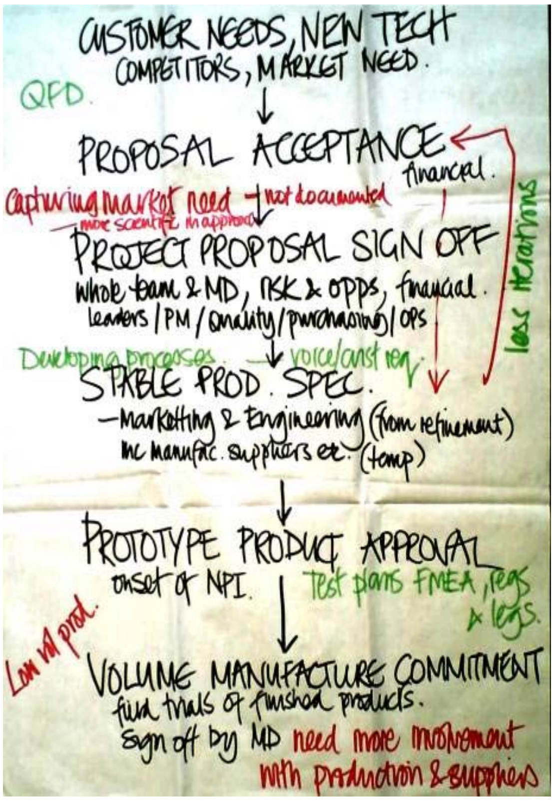

Figure 4.1: Example of a completed NPD process mapping worksheet

4.1.4 Innovation culture questions

This activity was used to gain some insight into the innovation culture of the organisation. An abridged version of the UK Design Council's 'Living Innovation' benchmarking questionnaire was used (Department of Trade and Industry, 2006a). Three sets of three questions covered the company's ability to 'inspire' its designers, 'connect' with its customers and suppliers, and successfully 'create' – take good ideas into manufacture. Each question was written on a separate small card. Respondents had to decide to what extent the statement on the card was true for their company at that time. Only one response was allowed per question and so the team had to reach a consensus and note it down on the question card by ticking the appropriate box of the four-point Likert scale (Likert, 1932) ('Strongly disagree' / 'Disagree' / 'Agree' / 'Strongly agree'). This consensus-seeking method was intended to promote discussion amongst the team and to obtain a response which was as representative of the company as possible.

4.1.5 Company visit plan

The research activities were organised as half-day workshops conducted separately for each company on its own premises. The workshops were completed by the researcher and the research assistant and lasted around three hours. The team of company representatives varied in size from two to six but always included as a minimum the Environment Manager (or the person responsible for compliance with environmental legislation) and the Design/Technical Manager. The programme for the visit varied according to the availability of the participants but was generally as follows:

- Presentation by the researchers on the latest developments in the WEEE, RoHS and EuP Directives followed by discussions on how they affect the company
- Supply chain pressures activity;
- Life Cycle Thinking activity;
- Factory tour;
- NPD process mapping;
- Innovation culture questions.

4.2 Findings from the preliminary industrial study

In order to facilitate inter-company comparison and benchmarking, a quantitative scoring system was developed for some of the activities. The scoring system for the activities and the company results is presented in the following sub-sections.

4.2.1 Supply-chain pressures activity

Companies who applied a greater number of environmental pressures on their suppliers than they received from their customers were deemed to be environmentally ‘pro-active’ in their supply chain, and vice-versa. Table 4.2 shows that, according to this criterion: only one company was considered to be ‘pro-active’ on environmental issues; half of the companies were found to be ‘reactive’; and the remainder were ‘neutral’.

Several of the companies commented that there had been an increase in the dialogue between the company and their supply-chain in relation to environmental issues in recent years. In most cases this dialogue appeared to be limited to issues directly relating to compliance with legislation such as the WEEE and RoHS Directives. The positive effect of this communication was that the majority of companies appeared to be on course to fully comply with the WEEE and RoHS Directives where necessary. Four companies had

Pressures	Company					
	I	II	III	IV	V	VI
From customers	-2	-2	-3	-2	-3	-2
To suppliers	+3	+2	1	+1	+3	+1
Total	+1	0	-2	-1	0	-1
Conclusion	Proactive	Neutral	Reactive	Reactive	Neutral	Reactive

Table 4.2: Results of the supply-chain pressures activity

received customer requests for information on wider issues such as if the company had an environmental management system. Only one company could give an example of how such communication had led to an improvement in the environmental performance of a product which was not directly related to legislative compliance.

4.2.2 Life cycle thinking activity

Figure 4.2 shows a completed life cycle thinking worksheet. A company was deemed to have made a 'substantial effort' within a life cycle phase (indicated by a star) if it was able to provide three or more examples of initiatives or methods to reduce the environmental impacts during that particular phase.

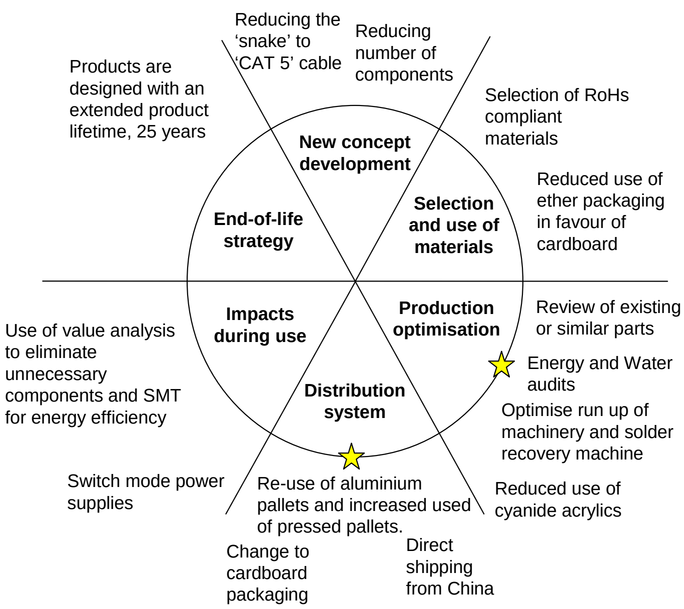

Figure 4.2: Example of a completed life cycle thinking worksheet

Table 4.3 shows the number of companies who have made 'substantial efforts' in each of the life cycle phases (indicated by a tick). It is noteworthy that five of the manufacturers have made substantial efforts to reduce environmental impacts through 'production optimisation'. This is logical given that improvements made to the production phase are likely to lead direct cost-savings for the manufacturer e.g. through reduced energy costs or waste minimisation.

Life cycle phase	**Companies making a 'substantial effort'**					
	I	II	III	IV	V	VI
New concepts	✓	✓				
Selection and use of materials			✓			
Production optimisation	✓	✓	✓	✓	✓	
Distribution system	✓		✓		✓	
Impacts during use				✓		
End-of-life strategy		✓			✓	✓

Table 4.3: Results of life cycle thinking activity

In contrast, just one manufacturer had made improvements to the 'impacts during use' of their products. The products of companies I, IV and V clearly have very significant impacts during their use phase and yet only one had made significant improvements in this area. The question therefore presents itself as to why the other two manufacturers had not yet attempted to make improvements in the use phase of their products' life cycle. In both cases the companies acknowledged that the use phase was likely to generate greatest environmental harm, therefore lack of awareness is ruled out. In fact, both companies explained that energy efficiency was not an important consideration for their customers, which was reflected in their product specification and requirement weightings.

Whilst a number of the environmental actions taken by the companies reduced the environmental impact of their products, none of the examples could be described as 'eco-innovative products', as the reductions in environmental harm appeared to be quite small.

Whilst undertaking the life cycle thinking activity participants often struggled initially to identify environmental actions that the company had taken. However, when a generic list of environmental actions was read to them they were often able to provide further examples of where the company had taken such actions. This was possibly because many of the positive 'environmental actions' taken by the company were in fact 'serendipitous' environmental actions, in that they were driven by cost rather than environmental issues.

4.2.3 Innovation culture questions

The innovation culture questions were scored by awarding +2 points for a ‘strongly agree’ response, +1 for an ‘agree’ response, and conversely -1 and -2 points were awarded for ‘disagree’ and ‘strongly disagree’ responses respectively.

Aspect of innovation culture	**Section score**						**Mean**
	I	II	III	IV	V	VI	
Inspire	5	3	1	4	3	3	3.2
Create	5	2	5	-1	6	-1	2.7
Connect	2	2	0	4	1	2	1.8
Total	12	7	6	7	10	4	

Table 4.4: Results of innovation culture questionnaire

From a maximum score of 18 (three sections of three questions worth two points each), Company I scored the highest total of 12 (Table 4.4). Given that the minimum score is -18, and all of the companies had a positive overall score, it is fair to say that the cultures of the companies were all generally supportive of innovation. However, none of the companies scored strongly in all three areas of the questionnaire. The mean scores for three different cultural aspects indicate that the companies struggled most with the ‘connect’ aspect. This aspect referred to the companies’ efforts to engage with their external environment (e.g. customers, suppliers, developments in legislation etc.) in order to focus innovation activities. Interestingly, all but one of the companies disagreed with the statement: “we see changes in regulation and legislation as an opportunity”. This suggests that although environmental legislation is often presented in the academic literature a driver for DfE, it may not be an effective driver for eco-innovation if companies do not perceive changes in legislation as an opportunity for innovation.

4.2.4 NPD process mapping

The NPD models were analysed with a view to identifying popular tools or methods and similarities or features of the process which might provide suitable ‘entry points’ for eco-innovation. None of the companies had any form of eco-design management system in place. Similarly, none of the companies included explicit environmental requirements within their requirements specification documents, other than to comply with legislative requirements. However, some potential entry points for eco-innovation were noted, as summarised in Table 4.5.

One general weakness of the NPD process mentioned by the majority of the companies was the difficulty in developing an accurate and stable requirements specification. Many

Common 'Strengths'	Company benefit	Eco-innovation opportunity
Use of Quality Functional Deployment (QFD)	Ensure that requirements specification accurately represents needs of customer	Promote use of 'QFD for the Environment' (Masui et al., 2001), which extends existing QFD tools by including the 'Voice of the Environment' to set environmental targets
Regular safety and compliance reviews	Avoid the negative company impacts of non-compliant or unsafe products	Include an environmental review as part of the safety review – check for environmental compliance and ensure environmental targets will be met
Strong emphasis on cost-management and designing to a price point	Ensure that product is price competitive within its market segment	Use of financial methods such as environmental accounting, or Eco-Value to emphasise cost benefits to company of eco-design

Table 4.5: Opportunities for eco-innovation within existing NPD process models

companies mentioned that projects progress, even when the requirements specification had not been formally agreed, or that changes to the specification were often made after it had been agreed. This was perceived as wasting engineering effort and slowing project progress. Academic literature suggests that the formulation of the requirements specification is a key stage for the integration of environmental considerations (Olundh, 2006). There are therefore opportunities for tools that can both improve the requirements specification formulation process and integrate environmental considerations.

4.3 Summary

A range of innovation and environmental benchmarking activities were completed with six companies within half-day workshops. This study contributed to the overall research by providing a better understanding of: the characteristics of 'real-life' NPD and innovation activities; what environmental pressures companies are facing; and how they are responding to these pressures. The findings from these activities included:

- Compliance with environmental legislation was found to be the main drivers for environmentally beneficial actions.
- Reducing manufacturing costs was also a significant driver for environmental action but companies had not generally considered the environmental benefits of these actions when deciding to undertake them.
- Communication on environmental issues is increasing in most supply-chains but generally remains limited to legislative compliance issues.
- A number of potential 'entry points' for eco-innovation tools were identified.

- In particular, there remains significant potential to improve the way in which environmental considerations are integrated into the requirements specification formulation process.

In the following chapter some of the insights from this study are used to help guide the development of a range of eco-innovation tools.

5 Development of the toolbox for eco-innovation

This chapter explains the process undertaken to develop the ‘toolbox for eco-innovation’. The aim of creating the toolbox was to be able to offer tools that could help with the various different activities that must be conducted during the front end of innovation.

A key decision at this stage was whether to develop new eco-innovation tools from scratch or to adapt existing innovation tools to the requirements of eco-innovation. It was decided to adapt existing innovation tools for the following reasons:

- using tools that have previously been shown to improve creativity and innovation as the foundation of an eco-innovation tool should help to ensure that the outputs of the tool are genuinely innovative, as well as being environmentally beneficial;
- if an eco-innovation is based upon an innovation tool that is already known to the company or designer they might be more likely to adopt it, plus it is hoped that the learning requirement would be lower;
- the established reputation of the innovation tools might help give ‘authority’ or credibility to the resulting eco-innovation tools.

The main activities undertaken in the development of the toolbox for eco-innovation were:

- Developing a search strategy for identifying existing tools for innovation or ECD that might be appropriate for eco-innovation (Section 5.1).
- Applying the search strategy within a review of the academic literature (Sections 5.1 and 5.2)
- Reviewing the strengths and weaknesses of the identified tools with respect to eco-innovation (Section 5.3).
- Adapting the tools for eco-innovation (Section 5.4).
- Testing the tools through in-house trials (Section 5.5).
- Reviewing the results of the in-house trials and selecting the best tools to form the eco-innovation tool box. (Section 5.5.3).

Figure 5.1 provides an overview of these activities.

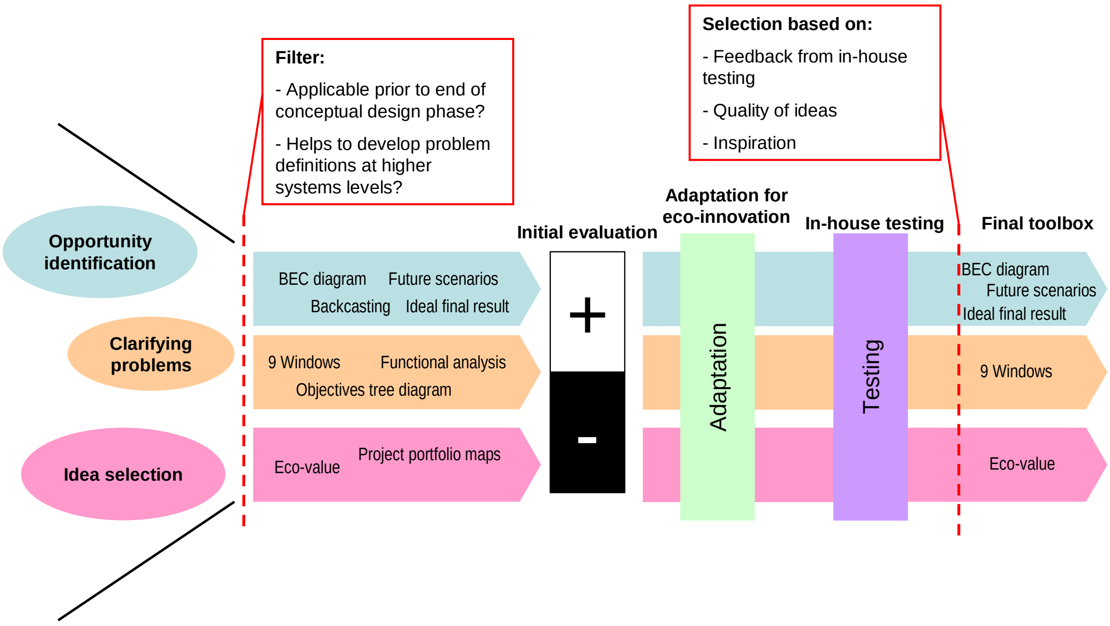

Figure 5.1: Overview of the development of the eco-innovation toolbox

5.1 Overview of the tool search process

There are hundreds, if not thousands, of tools described in the academic literature that are intended to provide support for engineering practitioners. It was therefore necessary to utilise some kind of logical process to help guide the search for tools that might be of benefit within the eco-innovative process. This section provides an overview of that process by first describing the search strategy and filter mechanisms used before going on to discuss some of the tools that were rejected and the reasoning behind those decisions.

The search for potentially relevant tools was narrowed in two ways. First, by considering the definition of the eco-innovative process developed in Section 2.1.2. This stated that an eco-innovative process is one that:

- considers the entire product life cycle;
- has a high level of environmental ambition;
- tackles problems at higher systems levels;
- focuses on the activities up to the end of the conceptual design phase.

The third and fourth characteristics from this definition were considered relevant to both ECD tools and 'normal' innovation tools and so were used as 'search filters' as part of the search strategy.

The second part of the strategy was the use of Koen's model of the front end of innovation, described in Section 1.1.3, to identify the type of activity that the eco-innovation tools might be used for. Koen's model suggests that there are five types of activity that occur within the front end of innovation:

- Opportunity identification
- Opportunity analysis
- Idea generation
- Idea selection
- Concept and technology development.

All of these activities are likely to be important for eco-innovation. However, it was decided to focus on 'opportunity identification', 'idea generation' and 'idea selection' as these activities were considered more likely to benefit from the use of workshop tools, the other two being predominantly research activities that can be conducted by individuals. Within the 'idea generation' activity it was decided to focus on the sub-topic of 'clarifying problems' as it was assumed that design teams in industry would have their own particular preferred manner for generating ideas. These two aspects of the search strategy therefore provided a good sense of the types of tools to look for. In practise, there was a third element to the search strategy that was used to eliminate certain tools. This was the feasibility of adapting tools such that they could be applied within the time and resource constraints of the research.

The next issue was where to look for such tools. As well as tools already well-known to the researcher, key texts from academic literature within the domains of engineering design and product development (Cross, 2000, Pahl and Beitz, 1995, Pugh, 1991, Ulrich and Eppinger, 2004) and innovation management (Tidd et al., 2005, von Stamm, 2003, Turner, 2003) were reviewed for examples of tools that passed the initial tool filters. Also, it was at this time that the researcher participated in a training course on TRIZ (Savransky, 2000) tools and biomimetics (Vincent et al., 2006) and so these tools were also examined.

From the search, nine tools that were potentially relevant for eco-innovation were identified. The selected tools are described in detail in the following section. The search could have been continued to identify more relevant tools but it was felt that the nine tools selected provided a sufficient range of tools for the purposes of the research. Furthermore, at this time the research faced pressure to advance the development of the tools as some of the industrial collaborators were keen to begin testing the eco-innovation tools. Table 5.1 provides a brief summary of some of the tools rejected as part of the tool search.

Tool function	Tool description	Up to conceptual design?	Considers higher systems levels?	Reason(s) for rejection
Opportunity identification	**Fishbone diagram** (Tague, 2004)**:** Often used to diagnose manufacturing defects, this tools attempts to identify the root cause of a problem by examining potential contributing factors from across areas such as 'people', 'methods', 'machines', 'materials', 'measurement', and 'environment'.	✓	✓	• The ability of the tool to promote consideration of higher systems levels will strongly depend on how the 'problem' is formulated. The tool provides no guidance on this.
	Delphi method (Rowe and Wright, 1999)**:** A group of experts in a particular field are asked for written opinions about future developments in the field. Through a series of rounds of questioning and evaluation, some form of consensus is sought.	✓	✗	• Requires the input of external experts and can take many months to organise and execute and so would be difficult to run as a short workshop session. • Experts' knowledge may be too focused to help identify opportunities, particularly if they involve new technologies that would supersede the incumbent technology.
Idea selection	**PEST analysis** (Turner, 2003): This is a method for reviewing a market that focuses on the Political, Economic, Social and Technological (PEST) factors that may affect the strategic attractiveness of that market now and in the near future.	✓	✓	• Both the SWOT and PEST analysis tools were rejected, despite passing the main filter conditions, because they perform a very similar function to the 'Future Scenarios' tool, described in Section 5.2.1. The additional benefit of the Future Scenarios tool is that it considers a longer time frame, which is important for eco-innovation as the outputs of eco-innovation projects will often take longer to develop and commercialise.
	SWOT analysis (Turner, 2003): Similar to PEST analysis but applicable to new business or product concepts. This encourages the user to consider the Strengths, Weaknesses Opportunities and Threats (SWOT) that the new proposition would face.	✓	✓	

Continued overleaf.

Tool function	Tool description	Up to conceptual design?	Considers higher systems levels?	Reason(s) for rejection
Problem clarification	**Method 635** (Pahl and Beitz, 1995): After being introduced to the problem, six participants each write down three rough solutions in the form of key words. They then pass their solutions along to their neighbour who must add three further solutions or developments. This process is repeated five times in total.	✓	✗	• A general 'idea generation' tool but does not help with 'clarifying problems'. • Does not encourage consideration of higher systems levels.
	TRIZ contradiction matrix and inventive principles (Mann, 2002b): Where a problem can be described in terms of a contradiction between two functional or physical requirements, the contradiction matrix can be used to identify a small number of the most relevant of the 40 'inventive principles' which may help to inspire ideas to overcome the contradiction.	✓	✓	• Requires a good understanding of the 39 parameters and the 40 inventive principles to use effectively and it is difficult to imagine how this learning requirement could be reduced. Would therefore take too long to learn and apply for a short workshop.
	TRIZ Su-Field analysis (Mann, 2002b): A system is made up of at least two 'substances' (read 'things') and at least one 'field' (some form of energy). This tool provides a notation system to map the interrelations between these elements. Comparing this map with maps of previously solved problems can help to identify generic solutions to the problem.	✓	✗	• This approach appears to lend itself to the analysis of specific, focused technical problems rather than the more holistic, higher systems level approach which is sought.
	Quality Function Deployment (QFD) (Cohen, 1995): This tool helps to understand the relative importance of customer requirements and translate them into technical performance requirements. This helps to ensure that key requirements are met and to can guide trade-off decisions.	✓	✗	• Requires a good understanding of customer requirements and product architecture and is therefore more suited to incremental innovation than more radical, higher systems level innovation.

Continued overleaf.

Tool function	Tool description	Up to conceptual design?	Considers higher systems levels?	Reason(s) for rejection
Problem clarification	**Biomimetics** (Vincent et al., 2006): This approach attempts to identify examples of where an analogous problem to the one being considered has been solved in nature in order to inspire novel solutions.	✓	✓	• The ability of the tool to promote consideration of higher systems levels will strongly depend on how the ‘problem’ is formulated. The tool provides no guidance on this. • Requires the guidance of an expert or an expert system to identify and understand potentially relevant biological analogies.
	Empathic design tools (Leonard and Rayport, 1997): The empathic design approach involves the use of tools and observation methods that are intended to help designer ‘get inside the head’ of their customers and hence build a better understanding of what they need, want and feel.	✓	✓	• To apply empathic design tools in a meaningful manner requires considerable time, effort, resources and a number of real-life users/customers. This was considered unfeasible within the constraints of the research.

Table 5.1: Examples of the tools rejected as part of the search of the academic literature.

5.2 Introduction to the nine initial tools

This section describes the nine tools identified from the tool search as being potentially relevant for eco-innovation. The first four tools described here are relevant for 'opportunity identification'. These tools help to shape both product strategy and company strategy by guiding the company towards markets or technologies in which there is scope for eco-innovation. Subsequently the 'idea selection' tools of 'Eco-value' and 'Project Portfolio Maps' are described. These tools can be used to evaluate and prioritise competing concepts. The remaining three tools are intended to assist the design team with the task of 'clarifying problems'. These tools are relevant for the very early stages of an innovation project when an opportunity has been identified but it is not yet clear exactly what the user requires or what technical problems must be overcome. These tools are therefore used at a slightly more operational level than the more strategic opportunity identification and idea selection tools.

5.2.1 Opportunity identification - Future Scenarios

Future Scenarios is one of a range of 'futures studies' methods that aim to help companies in strategic decision making by considering the future. Future Scenarios and Backcasting, described in the following sub-section, are two futures methods that are considered to be more appropriate for the highly complex, long-term problems of sustainability where more mathematical and statistical methods such as Forecasting often struggle (Dreborg, 1996).

Future Scenarios exercises have been used by a variety of large corporations including Royal Dutch Shell who investigated future variations in global energy demand and supply (Shell Group, 2007), and Philips, who in 1995 developed new 60 product ideas for the year 2005 based on their analysis of socio-cultural and technology trends as part of their 'Vision of the Future' project (Philips Corporate Design, 1996).

The development of Future Scenarios as a formal method cannot be attributed to any one author but the work and writings of Peter Schwartz and colleagues at Shell during the 1970s significantly raised the profile of the method. Schwartz (1991) has identified eight main stages in a Future Scenarios activity:

1. *Identify the focal issue or decision* – What question are we trying to find an answer for by completing this activity? (e.g. 'should we move our production operations to China?').
2. *Find the key forces in the local environment* – What are the particular problematic issues contributing to this problem? (e.g. rising employment costs, constraints on expansion at existing production sites).

3. *Identifying the driving forces* – Why are these issue a problem for us? (e.g. low-cost competitors, increasing power of workers' unions in Europe).
4. *Ranking by importance and uncertainty* – Which of these issues are we certain will have a major impact on us, and which issues do we think may affect us?
5. *Creating and selecting scenario logics* – Given the issues and trends that we have identified as important, what sort of interplay would be possible between some of the issues and what different combinations of key factors can we imagine? (e.g. 'low-cost competition/high union power' vs 'differentiation competition/low union power').
6. *Fleshing out scenarios* – Taking the three most interesting scenario logics created previously and making them in to vibrant, realistic scenarios. (e.g. what would the world look like in the 'low-cost competition/high union power' scenario?).
7. *Implications* – In the world that we have envisaged, how would taking option A or option B affect us? (e.g. if we moved to China and union power increased there too, we may not achieve the cost-reduction benefits predicted).
8. *Selection of leading indicators and signposts* – How will we know which of the futures we have envisaged is closest to reality? What key events would happen on the way to scenario I as opposed to scenario II? (e.g. if China supports a UN international law on workers' rights then we are heading towards the 'low-cost competition/high union power' scenario).

One criticism of Future Scenarios methods is that, like several other forecasting methods, they are based on dominant trends and hence they are unlikely to generate solutions that would presuppose the breaking of trends (Dreborg, 1996). Therefore, in situations in which discontinuities may eventually occur, or are even deliberately sought after – as is the case with the radical changes needed for sustainable development, a Backcasting approach may be more appropriate. This issue is discussed further in the following sub-section.

Typical outcomes from this tool

- Range of scenarios which can be used for product and business strategy planning.

Why might this tool be useful for eco-innovation?

- Eco-innovations will be developed over years, possibly decades and so it is important to understand how the competitive landscape might develop over time when planning product strategy.

5.2.2 Opportunity identification - Backcasting

Backcasting is a term introduced by Robinson, but the original application is credited to Amory Lovins in his work on energy futures (Lovins, 1979). According to Robinson (1982):

> *The major distinguishing characteristic of Backcasting analysis is a concern, not with what futures are likely to happen, but with how desirable futures can be attained. It is thus explicitly normative, involving working backwards from a particular desirable future end-point to the present in order to determine the physical feasibility of that future and what policy measures would be required to reach that point.*

Dreborg (1996) suggests that Backcasting may be appropriate under the following conditions:

- when the problem to be tackled is *complex*, affecting many sectors and levels of society;
- when there is a need for *major change*, i.e. when marginal changes within the prevailing order will not be sufficient;
- when *dominant trends are part of the problem* - these trends are often the cornerstones of forecasts;
- when the problem to a great extent is a matter of *externalities*, which the market cannot treat satisfactorily;
- when the time horizon is long enough to allow considerable scope for *deliberate choice*.

The wording of this final point highlights the underlying philosophical difference between Backcasting and either forecasting or Future Scenarios. Implicit in a Backcasting approach is a belief in the ability of society to make strategic choices, break trends and select a new path; in short, it is a belief in free will. In contrast forecasting and future scenario methods are more aligned to a deterministic view of the world.

An example of the application of a Backcasting approach to the challenges of sustainable development is the work of Amory Lovins on the issue of energy production and consumption. Lovins first coined the term ‘soft path’ to describe an alternative future for the energy production and use within the US and provided a contrast to the ‘hard path’ being forecast by many industrialists at the time. The hard path saw a growth in the overall energy consumption with an increasing reliance on fossil fuels and later nuclear power in large centralised power generation systems. The soft path emphasised the importance of energy efficiency to reduce demand at source.

Lovins' work has been influential in shaping the views of policy makers, academic researchers, and to some extent the wider public. This, combined with the accuracy of Lovins' predictions of energy use in the USA, suggest that Backcasting might be a viable method for tackling the challenges of sustainable development.

To gain a better understanding of how companies might apply the principles of Backcasting to deal with their specific environmental impacts it is useful to consider the work of Byggeth *et al.* (2007). They have developed a 'Method for Sustainable Product Development' which integrates principles of sustainability, Backcasting and the concurrent engineering model of the NPD process. The method is intended to deal with issues of both ecological and social sustainability (but as social sustainability is outside the scope of this research this will not be considered). The method consists of the following:

- A manual which details the objectives and the theory of the method and instructions on how to use its different tools.
- A model of a NPD process, which includes phase-specific questions for various traditional aspects within the phases.
- Sustainability Product Assessment (SPA) modules, which include strategic guiding questions to identify potentially critical substances and activities during the life cycle of the existing or planned product and questions to generate proposals for improvements.
- A prioritisation matrix, which includes questions to facilitate evaluation and choice among proposals. Sustainability aspects are integrated with traditional economic and technical aspects to improve the applicability of the method from a business perspective.

Empirical testing of the method with two companies in Sweden concluded that the method was useful in: helping to identify potential sustainability problems of present or planned products caused by substances and activities during the product life cycle; and in finding solutions to the potential problems; and in stimulating new product and business ideas. Furthermore, Byggeth *et al.*(2007) argue that, 'Investment paths towards compliance with basic principles for sustainability can also help us avoid impacts, even impacts that are not yet described'. They emphasise the point that, '...improvement proposals should not only deal with current problems, but while doing so they should also be fruitful steps in a path towards sustainability.'

This last point highlights one of the strengths of Backcasting in that it provides a good overview, enabling decision makers to consider not only the current problems, but also the company's location in terms of following a path towards sustainability.

One issue with both the future scenario and Backcasting tools is that they require a significant amount of research to conduct properly. In the case of Future Scenarios the research is necessary to highlight current socio-cultural, technology and economic trends. For Backcasting the research requirement will come when attempting to define and assess the feasibility of the scenarios. Having said this, it could be argued that in most multi-national companies such costs could easily be absorbed and are comparable to expenditure associated with conventional forms of strategic planning. Furthermore, the potential dividends are high if a company can gain a significant competitive advantage by recognising a trend which had previously gone unnoticed or is prepared for the piece of legislation which takes the rest of the industry by surprise.

Typical outcomes from this tool

- Vision of a desirable future state.
- Plan of how to achieve the desirable future state.

Why might this tool be useful for eco-innovation?

- Many industries will require step-change improvements to become sustainable which break the 'business as usual' trends. Backcasting helps to imagine and achieve these types of step-changes.

5.2.3 Opportunity identification - BEC Diagram

The Business-Environment-Customer (BEC) diagram (O'Hare et al., 2007) is a tool developed by the author based on observations made during company visits which suggested that they struggled to recognise the environmental benefits often associated with their cost-driven actions. Recognition of this fact led to the development of the BEC Diagram, shown in Figure 5.2 below.

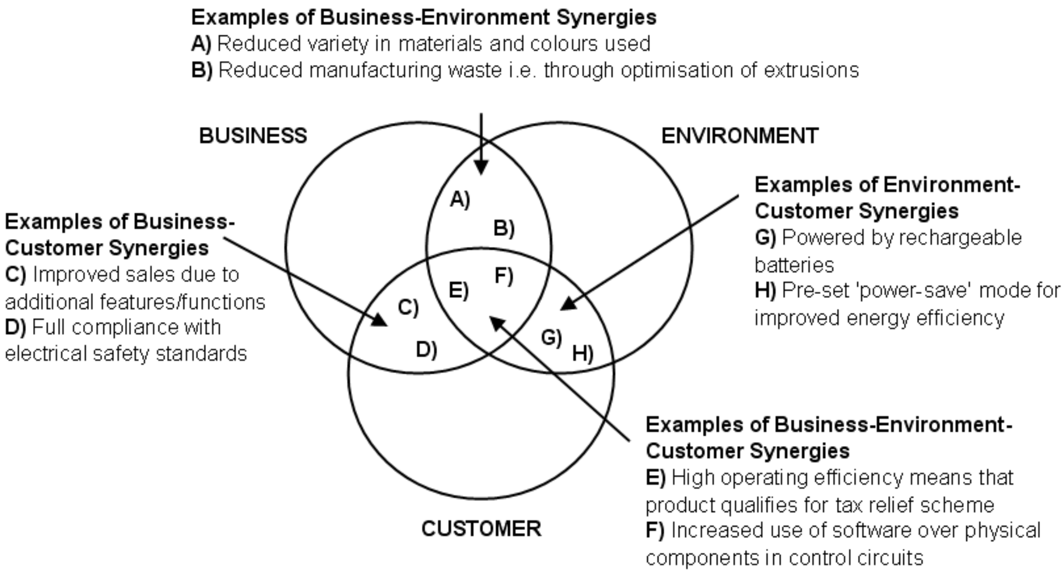

Figure 5.2: BEC Diagram showing the inter-relations between business, environmental and customer product life cycle requirements

The BEC Diagram is intended to represent and classify the inter-relations between the key stakeholder requirements of the product throughout its life cycle (referred to from now on as simply ‘product requirements’). Product requirements are positioned on the diagram according to the stakeholders for whom that particular requirement will provide a benefit. Figure 5.2 uses real examples taken from the six businesses visited during the preliminary study.

It is suggested that businesses may use the BEC Synergies diagram in the development of an eco-innovation project using the following procedure:

4. List the major product requirements for the product on sticky notes, putting one requirement per sticky note.
5. Place the sticky notes on the BEC Diagram according to which of the stakeholders the requirement benefits, as in Figure 5.2. At this stage there should be sticky notes in various segments around the diagram.
6. Select a requirement that currently only benefits one or two stakeholders and think about how the product would have to change in order for the requirement to benefit all three stakeholders. When a new product concept or feature is thought of that would mean that the requirement would benefit all three stakeholders it is noted down on the sticky note which is then moved into the centre segment.
7. Continue with this process until all requirements are in the centre or all opportunities are exhausted.
8. Evaluate the proposed product concepts or features and select ideas to be taken forward.

By clearly segregating the product requirements in terms of how they will benefit the major stakeholders, the BEC Synergies diagram is a tool that companies can use to review their current business activities and the focus of their design efforts and identify opportunities for improvement.

The tool shares some similarities with the Eco-Value Analysis (Eco-VA) tool proposed by Sakao *et al.* (2006) which draws on statistical methods, Service Engineering principles and Value Analysis to quantitatively evaluate the benefit to the customer, the business and the environment of different product concepts. The BEC Diagram also encourages the designer to consider the requirements of these three different stakeholders, however, it does not attempt to quantify the benefits as it is aimed at generating concepts rather than the robust analysis of competing concepts which is the strength of the Eco-VA method.

One limitation of the BEC Synergies diagram is that the customer is represented as one homogenous entity. Recent work has noted that the marketplace comprises a diverse range of customers with different requirements. This issue is overcome by the 'Eco-value' concept described in Section 5.1.5.

Typical outcomes from this tool

- Ideas for new products or business models.

Why might this tool be useful for eco-innovation?

- If the design team can imagine situations in which improvements to the environmental performance of a product would also benefit the company and the customer, significant improvements to environmental performance would then become a goal rather than a burden.

5.2.4 Opportunity identification - Ideal Final Result tool

The Ideal Final Result tool and the 9 Windows tool described in the Section 5.1.9 are both part of the ‘TRIZ’ tool set. TRIZ is a Russian acronym which translates as 'Theory of inventive problem solving' which was developed by Genrich Altshuller and his colleagues from 1946 onwards. TRIZ is a methodology, tool set, knowledge base, and model-based technology for generating innovative ideas and solutions. TRIZ has been defined as ‘knowledge-based systematic methodology of inventive problem solving' (Savransky, 2000).

Of the many TRIZ tools available, two were found to be potentially relevant for eco-innovation: the 'Ideal Final Result' and the '9-Windows on the World'. Both tools are primarily designed to help suppress a designer's 'psychological inertia'. Psychological inertia is a concept drawn from cognitive science. It is analogous to physical inertia which is the effort made by a system to preserve the current stable state or to resist change in that state. Complex problems often require the problem solver to change their view of the elements of a system in order to reach a new understanding of the system and subsequently find a solution. Psychological inertia increases the time and effort required to make such changes of view and hence makes inventive problem solving more difficult and time consuming.

When tackling an eco-innovation project it is likely that designers will bring with them firmly fixed ideas about what customers want; what technologies will meet those needs; and how they should be designed - in short, considerable psychological inertia. Therefore any tools which might help designers to suppress this psychological inertia will be useful for eco-innovation.

The Ideal Final Result (abbreviated IFR) is an implementation-free description of the situation after the problem has been solved. It focuses on the customer’s functional needs and hence it is particularly relevant for the purposes of eco-innovation. It is designed to address the root cause of a problem by thinking about the solution, not the intervening problems (Savransky, 2000).

One of fundamental aims of TRIZ is to move systems towards an ideal state whereby the system benefits are progressively increased whilst decreasing system cost and harm (Savransky, 2000). The end point of this evolution is the Ideal Final Result. The ideal system delivers the benefit required and yet has no weight, occupies no space, requires no labour and requires no maintenance. The ideal system is therefore impossible to achieve, but simply by reframing the problem in a way that *attempts* to achieve the ideal system can lead to breakthrough solutions (Domb, 1997a).

In practice, when applying the IFR method, the design team should first try to describe the solution to their technical problem independent of the mechanism or constraints of the original problem. The language used to describe this solution should be as simple as possible and should not include any technical or domain-specific terms as such language will often be associated with the existing problem or existing solutions. It can be very difficult to formulate a suitable IFR statement and so when a first attempt is made it should be checked against the following four characteristics of a true Ideal Final Result (Domb, 1997a):

- eliminates the deficiencies of the original system;
- preserves the advantages of the original system;
- does not make the system more complicated (uses free or available sources);
- does not introduce new disadvantages.

Once an IFR statement which meets these criteria has been formulated, a number of novel ideas will start to be developed into solutions. However, if no promising ideas are forthcoming, Domb (1997b) suggests using the following four steps taken from ARIZ (the Algorithm for Creative Problem Solving):

1. What is the final aim?
2. What is the ideal final result?
3. What is the obstacle to this?
4. Why does this interfere?
5. Under what conditions would the interference disappear? What resources are available to create these conditions?

In review, the Ideal Final Result method would appear to be a useful method for suppressing the psychological inertia of a designer or design team. One concern is that, whilst there are numerous hypothetical examples of the application of TRIZ and the IFR tool, there is little documented evidence of the industrial application of TRIZ. It would however seem to be particularly appropriate for eco-innovation as it favours the development of high-level solutions which tackle problems at their source (Jones, 2003).

Typical outcomes from this tool

- New viewpoints on a problem.
- Ideas for new products.

Why might this tool be useful for eco-innovation?

- Should help to generate problem definitions at higher systems levels by reducing psychological inertia and forcing the design team to focus on the fundamental need of the user.

5.2.5 Idea selection – Eco-value

According to Pascual and Stevels (2006) the managerial dimension of EC is relatively understudied compared to the environmental and technical aspects. Therefore to assist managers with managerial issues such as selecting the type of markets and price points to aim for with new products they have proposed the concept of 'Eco-value'. Eco-value is defined as the ratio between consumer price and environmental load of products/services i.e.

$$\text{Eco-value} = \frac{\text{Retail price}}{\text{Environmental impact}}$$

From this it will be seen that services, such as management consultancy services which have a high cost but a low environmental impact, will typically have a high Eco-value – which is good from an environmental perspective. In contrast, a low Eco-value product might be a tungsten filament light bulb which is cheap to buy but has a large environmental impact due to the energy it uses.

The key underlying assumptions of Eco-value are that within a given market the wealth available to purchase products and services (i.e. the ‘spending power’) is limited and that the aim of a company’s environmental strategy must be to reduce the overall environmental impact of that spending power (i.e. the consumption).

This assumption contrasts with the conventional ECD philosophy which is to reduce the environmental impact of any given product to an absolute minimum. Pascual and Stevels argues that this conventional approach to ECD leads to the development of products that are ‘greener’ but are not particularly commercially successful as they have sacrificed some functionality or 'appeal'.

This also leads to the problem of ‘rebound effects’ because in order to compete with 'conventional', mass-marketed products, greener products may have to have a lower retail price than their conventional competitors in order to compensate for their reduced functionality. If something is cheaper then it is likely that more of it will be sold, causing a net increase in consumption and environmental impacts. This is what is termed a ‘direct rebound effect’. Alternatively, if a product is cheaper to buy or operate due to improved environmental performance, the consumer may use the money they save to pay for a holiday to America. The environmental impact of the holiday to America may be considerably higher than the impacts ‘avoided’ in the original product. This is an example of an ‘indirect rebound effect’. Rebound effects are always a threat when using a conventional ECD approach. For this reason it is suggest that Eco-value is an important and promising approach to reducing the risk of rebound effects.

The main application of the Eco-value concept envisaged by Pascual and Stevels is in the development of alternative strategies which meet the needs of a diverse range of buyers whilst improving the overall Eco-value of consumption of a market. This can be done by producing a range of products at various price points which aim to maximise Eco-value rather than trying to minimise environmental impacts.

In order to compare products in terms of Eco-value it is necessary to have a quantitative assessment of their environmental performance. Ideally this would be completed using LCA software such as Ecoscan which provides outputs results in terms of a single aggregated score. As this type of tool is currently only used by a limited number of companies the authors suggest that other physical units such as weight, volume, energy etc. can also be used as alternative units for environmental performance.

Pascual and Stevels (2006) claim the following benefits are associated with the use of Eco-value:

- Provide a common language - Both engineers and managers can easily understand and interpret Eco-value results;
- Informed decision making - Eco-value provides the basis for decision making based on facts. It addresses the question; for a specific target group, which design alternative provides higher profitability?
- Align environmental and business strategies - Value-based strategies and Eco-value align ECD with overall business strategy by addressing the ultimate goal of the company: value creation.

Typical outcomes from this tool

- Comparison of products in terms of eco-value.

Why might this tool be useful for eco-innovation?

- Offers several new strategies for a company to improve their environmental performance whilst still delivering a competitive range of products.
- May help to overcome ‘rebound effects’.

5.2.6 Idea selection - Project Portfolio Maps

Portfolio management is a dynamic process for evaluating, selecting and prioritizing new projects and to compare the projects with already existing ones (Cooper et al., 1988). Four main goals are put forward for performing portfolio management (Cooper et al., 2002):

- maximize the value of the portfolio by identifying and eliminating unprofitable products;
- align the portfolio with the overall business strategy;
- balance the portfolio to gain the right mix of projects; and,
- select the right number of projects.

It has been suggested that the portfolio management process represents an important opportunity to integrate environmental considerations into the pre-specification phase of product development (Olundh and Ritzen, 2004). Furthermore, this type of activity may have wider benefits for companies that do not currently undertake formal portfolio management.

The activity of portfolio management usually involves the following sequential activities (Archci and Ghasemradeh, 1999):

1. Proposals – gathering together all the possible and existing NPD projects that a company could invest in.
2. Pre-screening – eliminating proposals that do not meet fixed business requirements e.g. ‘Must have a European market worth at least £500 million’.
3. Individual project analysis – data gathering and analysis to build up a more detailed and comprehensive picture of the project.
4. Optimal portfolio selection – comparing the relative merits of the projects compared to overall business strategy.
5. Portfolio adjustments – the on-going process of reviewing the portfolio in light of developments of the company context and making further investments or divestments as appropriate.

The main area of interest in this process is the ‘optimal portfolio selection’ activity which is normally based around a 'product portfolio matrix'. The product portfolio matrix is conventionally shown as a 2x2 matrix with axes of 'market growth' and 'market share/profit'. The Boston Consulting Group gave names to the four quadrants as shown in Figure 5.3. For sustained profitability a company must aim to have as many existing products or product concepts as possible in the 'stars' quadrant which have both good market share and good growth. 'cash cows' are mature products which should be 'milked' for maximum profitability until the market disappears. 'question marks' have potential to become Stars but will require careful management in order to increase market share.

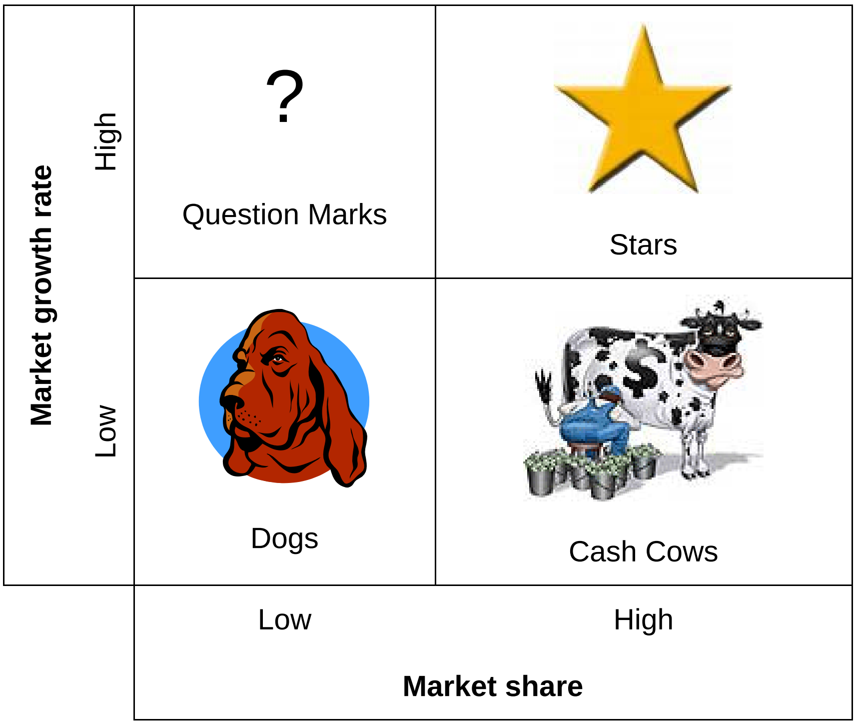

Figure 5.3: The Boston Consulting Group product portfolio matrix (Henderson, 1979)

Finally, 'dogs' are failing products in an unattractive market and hence should be considered for divestment from the portfolio.

Eagan and Hawk (1995) have attempted to extend the popular product portfolio matrix tool to the field of eco-design. They suggest that changing the axes to 'opportunity' and 'exposure' are more appropriate when using the product portfolio matrix as a type of risk assessment tool. They also introduce the third axis of 'environmental burden' which is an indicator of a products environmental impact, as shown in Figure 5.4. Eagan and Hawk go on to present generic environmental management strategies for each of the four quadrants. For example, existing products or product concepts in quadrant I will generally receive little in terms of management of economic resource and hence if a streamlined LCA of the product discovers any major environmental burden associated with the product then this would be a good justification for discontinuing the product. In contrast, star products in quadrant IV should be analysed with a full LCA. Any significant environmental burdens discovered should be dealt with immediately and with maximum resources as these are the company’s flagship products and hence any negative publicity associated with the environmental burdens of those products could be damaging to the company brand.

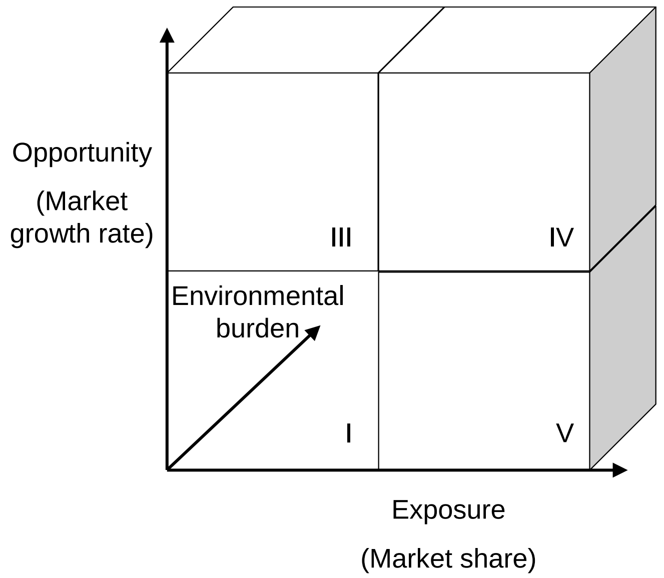

Figure 5.4: The product portfolio matrix adapted for eco-design (Eagan and Hawk, 1995)

The product portfolio matrix adapted for eco-design by Eagan and Hawk appears to be a simple but useful method for analysing opportunities and apportioning resources in terms of DfE effort and expenditure. Whilst the details of the strategies suggested by Eagan and Hawk might not be in accordance with the thinking of all product managers, the principles behind the method seem to be applicable to most companies. Furthermore, the product portfolio matrix is a well known management tool and hence it will be familiar to most managers and helps to link eco-design considerations into strategic management.

Typical outcomes from this tool

- Comparison of products in terms of economic and environmental performance.

Why might this tool be useful for eco-innovation?

- Integrates environmental considerations into the portfolio management activities which dictate which ideas are taken forward to NPD.
- By highlighting poor environmental performance as a business risk, it helps to create the business case for investing in eco-innovation activities.

5.2.7 Clarifying problems - Objectives Tree Diagrams

One of the outputs of opportunity identification tools will often be a marketing brief for a new product such as: ‘There is a need for an ultra-low energy consuming system for automatically preparing tea to be used within the home and with a retail price of £40-45’. Whilst this statement narrows down the project to a specific type of consumer product, it is not yet sufficient to explain to the designer what the product is required to do. Ambiguity still remains e.g. what level of automation is required? How many watts constitutes 'ultra-low power'? etc. The only unambiguous part of this statement is that it must have a retail price of £40-£45. A clear set of objectives are therefore needed before a designer can make any progress towards developing a suitable solution.

One method which has been proposed to help with this process of clarifying objectives is that of the 'objectives tree' (Cross, 2000). An objectives tree shows in a diagrammatic form the ways in which different objectives are related to each other, and the hierarchical pattern of objectives and sub-objectives.

The benefits of formulating an objectives tree during the earliest stages of a design project are that it helps to clarify the objectives and to ensure agreement between clients, managers and design team members.

The procedure for developing an Objectives Tree Diagram is as follows:

1. *Prepare a list of design objectives* – these are obtained either from the design brief or through questioning of the client. In the latter case, asking 'what is meant by that statement' will often help to tease out a greater level of detail.

2. *Order the list into sets of higher-level and lower-level objectives* – as the list develops the designer should be able to recognise that some objectives are of a higher order than others. Sub-objectives for meeting higher order objectives will also emerge. In some cases these lower order objectives will be means to fulfilling higher order objectives. As a multitude of levels of specificity develops, the list can be rewritten to represent the objectives hierarchy and also group them by the higher order objective that they help to fulfil.

3. *Draw a diagrammatic tree of objectives showing hierarchical relationships and inter-connections* – certain sub-objectives may relate to more than one higher order objective and hence all significant connections should be identified and drawn in.

An example objectives tree for the automated tea maker project is shown in Figure 5.5 Note that following paths down the tree explains *how* an objective might be fulfilled with increasing specificity whereas following paths up the tree explains *why* the sub-objectives are necessary.

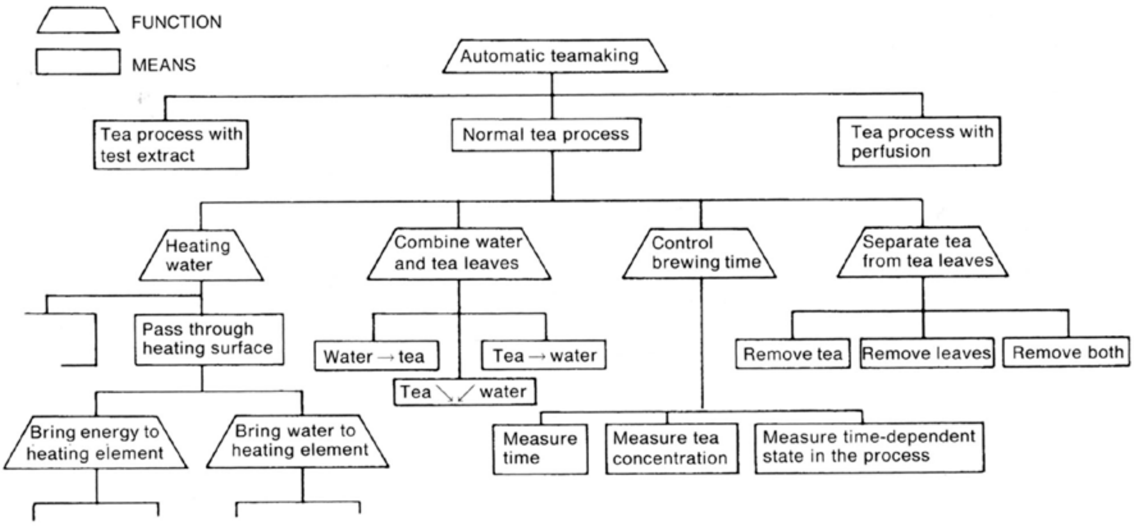

Figure 5.5: Example of an Objectives Tree Diagram for an automated tea maker (Cross, 2000 p.72)

In review, the Objectives Tree Diagram is a relatively simple and straight-forward method for mapping the objectives for a product. It also seems reasonable to claim that the process of developing an objectives tree will be useful for improving communication with the customer or within the design team in terms of having a universally agreed set of objectives. The two possible concerns with this method are that with a more complicated product than an automatic tea-maker, the diagram might become very complicated and hence difficult to plot and interpret. Secondly, it focuses purely on the functional aspects of a product and hence there is a risk that less tangible aspects of a product or service i.e. aesthetics, emotional appeal etc are overlooked.

Typical outcomes from this tool

- A map of the main objectives and functions of a product concept.

Why might this tool be useful for eco-innovation?

- Improved understanding of customers needs.
- By focusing on objectives and functions, it may encourage the design team to consider alternative means of fulfilling those functions which deliver better environmental performance.

5.2.8 Clarifying problems - Functional analysis

The objectives tree method and other tools described previously have highlighted the fact that engineering design problems can be tackled at many different levels. For example, it is a very different task to design a telephone handset than it is to design a telecommunications system. The client will often have some expectation of the level at which a problem is to be solved however, as Cross (2000, pp.77) states,

…there are often occasions when it is appropriate to question the level at which a design problem is posed. A client may be focussing too narrowly on a certain level of problem definition, when a resolution at another level might be better, and reconsidering the level of problem definition is often stimulus to the designer to propose more radical or innovative types of solution.

Functional Analysis is a method which has been developed to help clarify at what level it would be most appropriate to solve a design problem. As the eco-innovative process aims to 'tackles problems at higher systems levels', this would appear to make Functional Analysis a good candidate for inclusion in the eco-innovation toolbox.

The procedure for Functional Analysis involves five steps as summarised by Cross (2000, p.81):

1. Express the overall function for the design in terms of the conversion of inputs into outputs. The overall black box function should be broad, widening the system boundary, as shown in Figure 5.6.

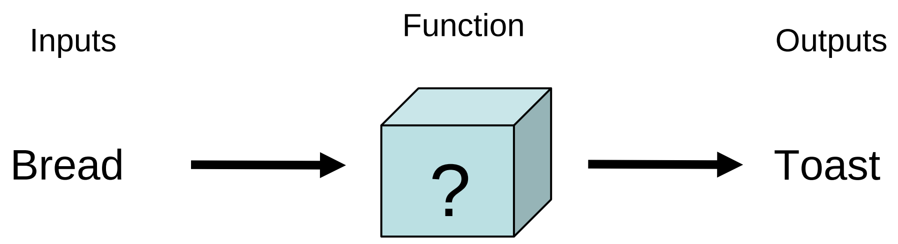

Figure 5.6: Example of the black box systems model

2. Break down the overall function into a set of essential sub-functions. The sub-functions comprise all the tasks that have to be performed inside the black box.
3. Draw a black box diagram showing the interactions between sub-functions. The black box is made transparent, so that the sub-functions and their interconnections are clarified, as shown in Figure 5.7.
4. Draw the system boundary. The system boundary defines the functional limits for the product or device to be designed.
5. Search for appropriate components to perform the sub-functions and their interactions. Many alternative components may be capable of performing the identical functions.

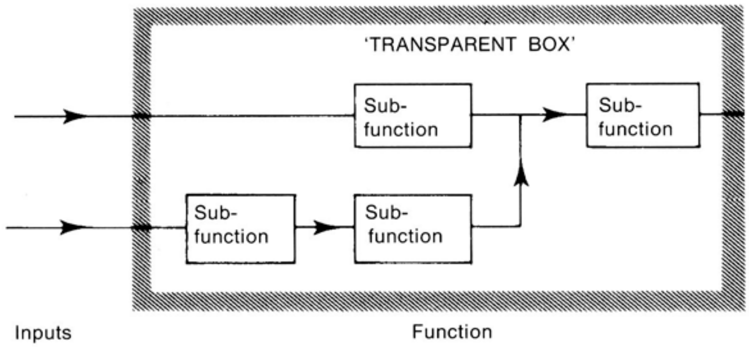

Figure 5.7: Transparent box revealing the interactions of sub-functions (Cross, 2000 p.80)

Functional Analysis is suggested as being particularly appropriate for the design of flow-process systems. Consider the example of a factory in which animal feedstuffs are bagged. The factory owners want to reduce the high costs associated with the handling and storing of the feedstuffs. A conventional approach might consider how each individual task within the factory (mixing, weighing, stitching bag, loading wagon, storing etc.) might be improved. Functional Analysis promotes the thinking that a broader formulation of the problem may be more appropriate, as shown diagrammatically in Figure 5.8.

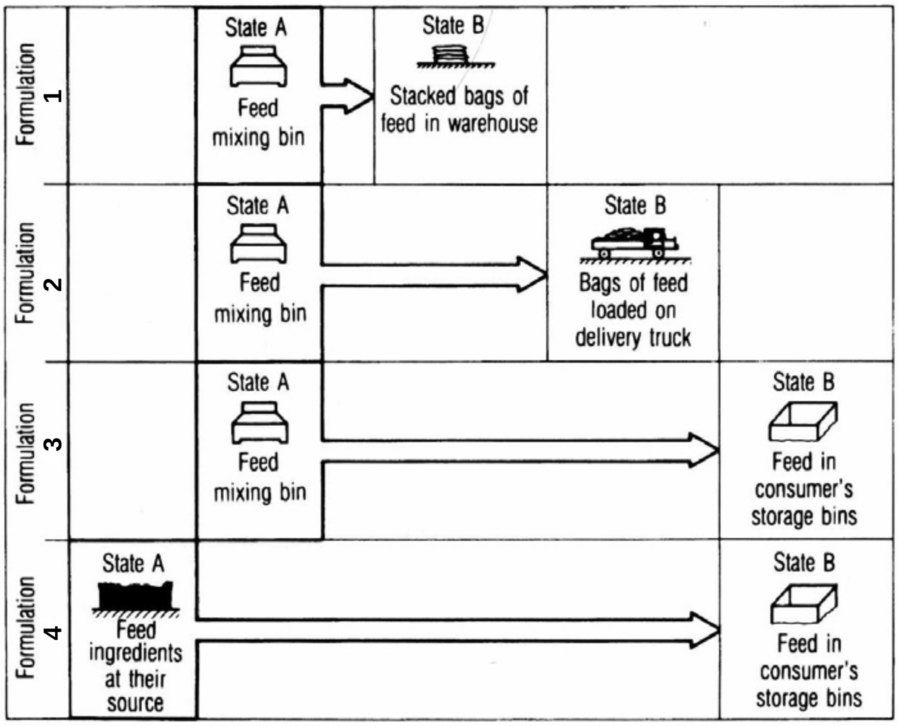

Figure 5.8 Alternative formulations of a feed distribution problem (Krick, 1976)

With each subsequent broadening of the formulation the designer is working at a higher level within the system which will include more degrees of freedom. With greater freedom it is perhaps more likely that the designer can formulate a solution that completely eliminates the 'no value added' sub-functions of handling, storing and loading. The idea that working at higher levels within the overall system will lead to more radical improvements is one which has also been expressed within eco-innovation literature (Jones, 2003).

One possible drawback of the Functional Analysis is that, like the Objectives Tree Diagram, it focuses purely on functional aspects which might mean that less tangible aspects of a product or service i.e. aesthetics, emotional appeal etc. are overlooked.

Typical outcomes from this tool

- A number of alternative formulations of a problem.

Why might this tool be useful for eco-innovation?

- Encourages the definition of problems at higher systems levels.

5.2.9 Clarifying problems - 9 Windows on the World

The ‘9 Windows on the world’ (9 Windows) tool aims to help think about a problem from different perspectives in space and time. The method splits 'the world' into nine windows. Psychological inertia means that when confronted with a problem most people will think about the system in the present, shown in the middle box of Figure 5.9. Unfortunately thinking about the problem by looking through this one window may not reveal a suitable solution, and more 'ideal' solutions may only become apparent through some of the other windows.

By considering the problem from a range of different temporal or spatial viewpoints a whole new range of issues become apparent, some of which may lead to innovative ideas.

The 9 Windows tool has been adapted for use in combination with other creativity or business tools such as SWOT analysis and Neuro-Linguistic Programming (Mann, 2002a). However, the description provided above outlines the fundamental ideas and execution of the method.

It is suggested that the 9 Windows method may be useful for the purposes of eco-innovation because:

- considering the problem at various points along a temporal scale would appear to fit very well with the principles of 'life cycle thinking' e.g. the labels 'Past', 'Present' and 'Future' could be replaced with 'Manufacture', 'Use' 'End-of-Life'; also,
- by considering the problem at various different spatial or system levels it may help to define problems at a higher, or lower, systems level which may lead to greater improvement potential from an environmental viewpoint (Jones et al., 2001b).

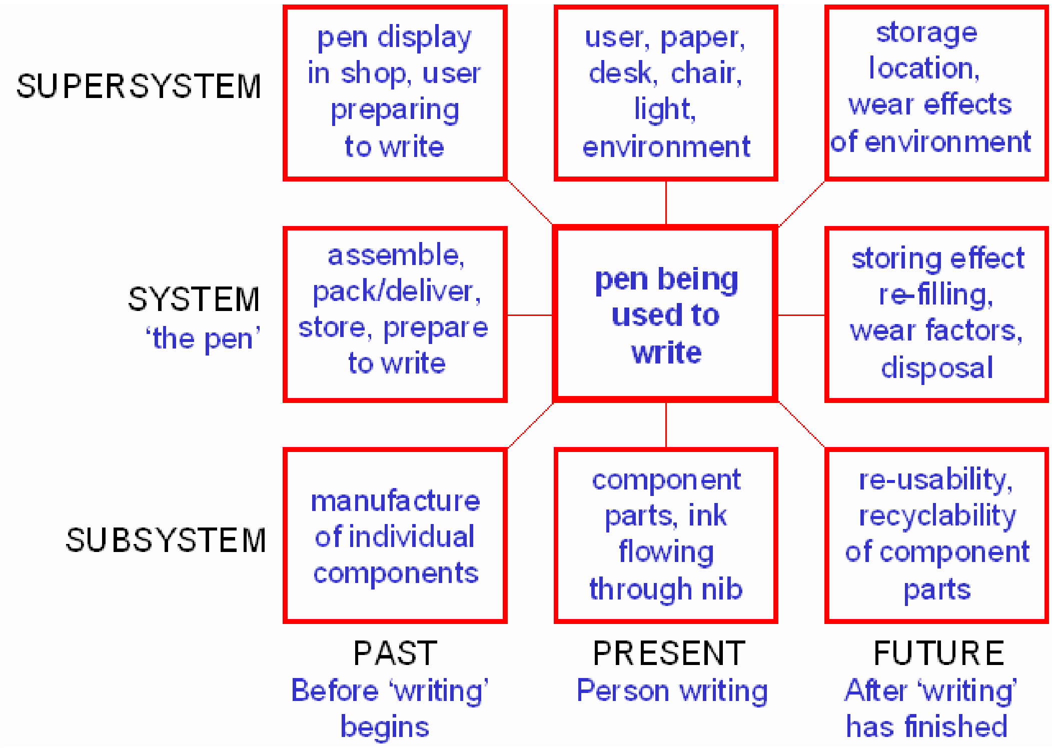

Figure 5.9 Example of the 9 Windows tool

A couple of problems exist with using the 9 Windows method in its most basic form as shown in Figure 5.9. First, the definition of what is the 'future', or what is the 'subsystem', is clearly subjective. These scales are continuums which stretch from the 'Big Bang' to the unforeseeable future, and from the sub-atomic to the galactic and hence determining which points on these continuums from which it might be insightful to view the problem is left to the judgement of the problem solver. Clearly, these points will need to change according to the nature of the problem being tackled. Another problem is that to fully explore a problem from nine different viewpoints can be very time-consuming and perhaps too mentally taxing for one session. It is suggested that this problem can be overcome to some extent by either the session facilitator limiting the search to the four or five windows which seem most likely to provide an interesting insight into the problem, or by splitting the task over a number of sessions.

Typical outcomes from this tool

- Eight alternative views on a problem.

Why might this tool be useful for eco-innovation?

- Provides a systematic approach to developing alternative formulations of a problem.

5.3 Assessing the suitability of the innovation tools for eco-innovation

The major strengths and weaknesses of the innovation tools as they currently stand from an eco-innovation point of view are summarised here:

Opportunity identification tools

Future Scenarios - Future Scenarios are based on extensive research of current trends both within the internal and external environment of the company. Such research is time consuming and expensive. However, once a range of plausible and interesting scenarios have been developed Future Scenarios would appear to be very powerful for stimulating creativity during the early stages of eco-innovation and informing company strategy.

Backcasting – significant time and resources are necessary to develop a scenario for a ‘sustainable future’. It has the advantage over Future Scenarios in that it sets a path to a sustainable future and not just ‘what is best given the current circumstances’, which might not necessarily be sustainable in the long-term.

BEC Diagram – Is quick and simple to apply and could easily be interpreted by both designers and managers. However, it supposes that all stakeholders have the same requirements and hence does not support product differentiation.

Ideal Final Result tool – May be useful in helping design teams to overcome psychological inertia and therefore pave the way for more radical solutions. However, the formulation of the IFR statement can be challenging (Domb, 1997b).

Idea selection tools

Eco-value – Requires the use of an aggregated LCA method such as EcoScan which is expensive, and resource intensive to apply. Furthermore it requires high quality data to obtain meaningful results. However it represents an opportunity to avoid rebound effects and allows for a heterogeneous view of the market.

Project Portfolio maps – Well established tool within management and strategy practice, they are relatively simple to learn and apply. The previous adaptations made by Eagan and Hawk to incorporate environmental issues makes them very appropriate for eco-innovation.

Clarifying problems tools

Objectives tree Diagram - Quick and simple to apply and should promote communication between the product development team and the client. However, the diagram may become hard to understand when applied to complex products and the method does not explicitly consider environmental impacts in any way. Will miss any important aspects that are not directly related to engineering functions.

Functional Analysis – Can be applied quickly providing the user adopts the correct mindset i.e. thinking at higher systems levels. Will miss any important aspects that are not directly related to engineering functions.

9 Windows tool – One of the more popular TRIZ tools. Should help to ensure that a thorough and systematic search for more fruitful problem formulations is conducted. However, could prove to be quite time-consuming to apply.

5.4 Adapting the innovation tools for eco-innovation

In the previous section a brief qualitative review of the strengths and weaknesses of the nine initial innovation tools was presented. In this section the adaptations made to the tools to overcome some of those weaknesses and to make them more appropriate for eco-innovation are discussed.

The aim of adapting the innovation tools for eco-innovation was to ensure that the tools:

- had an environmental focus;
- were suitable for a workshop format; and,
- could be completed in a session of no more than a few hours.

Table 5.2provides a summary of the tools after the initial adaptations.

In the following section, the testing of the remaining nine tools through in-house trials is described and the findings presented.

Tool	Summary of post-adaptation activity	Adaptation for eco-innovation
Future Scenarios	Team provided with ‘Global trends & drivers’ across four themes and asked to generate a range of local trends and drivers relevant for the case study company. Team then rates drivers according to their importance and uncertainty and select three important issues from which to create a scenario. Scenario is ‘fleshed out’ and then team must generate ideas for new products that the case study company could sell in the future they have created.	• Pre-prepared set of ‘global drivers’ on topics such as ‘technology’, ‘people’ and ‘the environment’ to reduce data gathering effort • Must select at least one driver from the ‘Environmental’ theme
Backcasting	Team presented with a long term environmental problem faced by a case study company and asked to discuss and refine the problem. They then have to create a vision of the future in which the problem has been solved by filling in the blanks of a scenario set in the year 2030. Finally, the team uses the vision of the future to inspire ideas for product concepts that would help to achieve the sustainable future envisioned.	• Vision of the future must be environmentally sustainable • Focus on generating new product concepts rather than policy implications
BEC Diagram	Team asked to generate a list of the main product requirements for a new product. Requirements are listed on sticky notes and then placed on the BEC Diagram according to the stakeholders they benefit. Team must then generate ideas for how the product or business model could change to create more ‘tri-synergies’.	• Adapted from Eco-VA approach (Sakao et al., 2006) by creating a visual map of conflicts/ complementarities and eliminating quantitative assessment • Workshop activity rather than individual analysis
Ideal Final Result tool	Team asked to generate an IFR statement for a case-study problem. Must then work through ‘Structured thinking questions’ in order to elaborate the IFR statement and highlight barriers to achieving it. Finally, team must generate a range of solutions inspired by their IFR statement and their answers to the structured thinking questions.	• Team required to generate mind map of unsustainable aspects of current system • Focus on environmental problems
Eco-value	Team are provided with descriptions of the three types of customer within the European consumer goods market. Team use these descriptions to define the requirements for a new range of the case-study product for each of the market segments. Team generates a one-line marketing brief for each of their new product concepts.	• Adapted to inspire new product concepts rather than just retrospective analysis/benchmarking

Portfolio Maps	Team are introduced to case study company facing a portfolio management problem. Team must place the company's existing products and a number of proposed projects on portfolio map axes after Eagan and Hawk and then suggest what portfolio management actions they would take.	• Third axis on portfolio map for 'Environmental performance' • Using environmental performance as justification for eco-innovation
Objectives Tree Diagram	For a case-study product, the team are required to list the functions provided and the current 'means' of achieving them on individual sticky notes. These sticky notes are then arranged into a hierarchy so as to generate an Objectives Tree Diagram. The components associated with the major environmental impacts of the product are circled in red and then the team must generate new product concepts that eliminate the major environmental impacts highlighted.	• Using the diagram to highlight the major environmental impacts at the component level • Environmental problems as the starting point.
Functional Analysis	Team asked to generate a 'process-stakeholder' map for a particular environmental problem. Team then required to generate possible solutions to the initial problem by involving some of the stakeholders mentioned in the map.	• Introduction of the 'process-stakeholder' map • Focus on environmental problems
9 Windows	Team asked to select one environmental problem of a case study product to try and improve. Team use the 9 Windows tool to analyse the problem from different points along the spatial and temporal axes in order to highlight some of the 'contributing issues'. One or two of these contributing issues are then selected as the starting point as inspiration for new product concepts.	• Team required to select an environmental problem to focus on • Time scale changed to 'design and manufacture', 'use' and 'end of life'

Table 5.2: Summary of the tool activities for the in-house trials and the main adaptations made

5.5 In-house trials

The aims of the in-house trials were to evaluate the tools and to select the best tools to take forward for industrial application. In the following sub-sections the methodology for the in-house trials is explained, the findings are presented, and the final selection of tools is justified.

5.5.1 Methodology for in-house trials

The in-house trials consisted of five workshops held with academic colleagues from within the Department of Mechanical Engineering at the University of Bath. All of the participants held, as a minimum, an undergraduate degree in Mechanical Engineering and hence had a good understanding and some experience of the process of New Product Development.

In each workshop teams of four to six participants were introduced to one or two of the eco-innovation tools. All of the workshops were facilitated by the researcher. Sessions lasted for two-two and a half hours and the general format of the sessions was as follows:

- *Presentation* – brief introduction to eco-innovation and the aims of the research
- *Presentation* – introduction to eco-innovation tool 1
- *Activity* – application of eco-innovation tool 1 to a case study problem
- *Break*
- *Presentation* – introduction to eco-innovation tool 2
- *Activity* – application of eco-innovation tool 2 to a case study problem
- *Feedback* – complete feedback forms for both eco-innovation tools

For each tool, the team were set a different case study problem e.g. 'Recommend new projects aimed at significantly reducing the environmental impacts of a cordless power drill.' Unfortunately it was not possible to use the same case study product for every tool, which would have made direct comparisons between tools easier, for the following reasons:

- In four out of five of the workshops the team tested two tools. If they had been applying both tools to the same case study the results may have suffered from 'learning effects', or they may have deliberately censored themselves from mentioning ideas that had already been discussed previously.
- Conventional experimental methods for overcoming learning effects such as 'counterbalancing' were not possible as it would have required the same group of people to participate in several workshops which was not feasible.

- Because the aims of the tools vary significantly, from considering product concepts for 20 years in the future to generating requirements for a product that could be launched tomorrow, it would have been impossible to write a design brief that would have been relevant for all the tools.

Instead, it was decided to select case studies that would best demonstrate the principles of the tool such that the participants could quickly and easily see the potential benefit of using the tool and therefore give an informed opinion about the utility of the tool.

The feedback for both tools was completed at the end of the session to allow the team a short time to reflect on their experience before completing the feedback form. The feedback form itself consisted of five questions:

1. How easy was it to understand the principle of the tool?
2. How easy was it to apply the tool?
3. Has any new thinking come out of the use of this tool?
4. What did you not like about the tool?
5. Any additional comments?

The first two of these questions used a five-point Likert scale (Likert, 1932) with the scale ranging from 'very easy' to 'very difficult'. The aim of including this scale was to promote discussion amongst the team and force them to come to a consensus as they could only provide one response for the team. An audio recording of the feedback sessions was made to capture this discussion. A 'comments' box was provided for all of the questions so that the team could briefly justify their response. Question three required a simple 'yes/no' response but the team members were encouraged to describe in their comments what the 'new thinking' was i.e. a new product concept or a new approach to the problem. The final two questions simply required a comment.

5.5.2 Results of in-house trials

A summary of the performance of the nine tools tested within the in-house trials is shown in Table 5.3in which the 'Ease of principle', 'Ease of use' and 'Any new thinking' columns are taken from the completed feedback forms. The last two columns are the researcher's own summary of the strengths and weaknesses of the tools which are based on the comments from the feedback form, the associated discussion, the researcher's observations from the workshops, and the outcomes of the workshop.

A number of general points can be made about the results. First, conducting the feedback for both tools at the end of the session meant that the team would often end up discussing the merits of a tool *relative* to the other tool they had tested. An alternative approach would have been to conduct the feedback for the first tool before starting on the second tool. However, the feedback for the second tool may still have suffered from this phenomenon. For this reason, the workshop number is indicated next to the name of the tool in Table 5.3 so that the reader is aware of which tools were completed together within a workshop.

Secondly, each of the tools received a positive response to the ‘Any new thinking?’ question. Contrary to this, one participant stated that the product concepts emerging from the Objectives Tree Diagram could have been thought of without the use of the tool. It is unclear what the new thinking was in this case. This apparently falsely positive result was perhaps due to the participants not wanting to disappoint the researcher by stating that the tool had not led to any new thinking and had therefore failed. It is suggested that the type of participants and the context of the test contributed to this occurrence of ‘researcher effect’ i.e. the participants were colleagues of the researcher and had nothing to lose by offering overly positive, ‘friendly’ feedback. Whilst the context for the industrial tests was different, it was decided that in future tool workshops it would be specifically stated that negative feedback would not impact the quality or success of the research, in order to try to avoid similar types of researcher effect.

Thirdly, the ease of understanding and use scores were generally quite low, indicating that the teams found the tools to be easy to understand and apply. The main exception to this was the functional analysis tool which scored four for ease of the principle and two-three for ease of use. The feedback comments for this tool suggested that the main difficulty was in the creation of the Process-Stakeholder map for which there was insufficient guidance on how it should be constructed.

In the following section the selection of the tools to be used in the industry trials is made and justified.

Tool (Workshop number)	Ease of principle (1 Easy, 5 Hard)	Ease of use (1 Easy, 5 Hard)	Any new thinking? (Yes/No)	Main Strength	Main Weakness
Future Scenarios (4)	2	2/3	Yes	Quickly identified a wide range of opportunities. Tapped into knowledge of team of future trends	Ideas quite abstract – suggestion that there was not enough detail
Backcasting (2)	2	2	Yes	Scenario resulted in both product and business strategy ideas	Time consuming to complete analysis of ideas
BEC Diagram (5)	1	2	Yes	Promoted the 'win-win-win' philosophy	Idea generation and analysis were not clearly separated
Ideal Final Result (2)	2	3	Yes	Forces more radical thinking	Can become too abstract Lose sight of business and environment objectives
Eco-value (3)	3	1	Yes	Thought-provoking, controversial	Team could not see any difference from a conventional marketing approach
Portfolio Maps (5)	1	1	Yes	Provides clear comparison for early decision making	Very subjective without having good data to hand More relevant to management than design
Objectives tree (3)	1	3	Yes	Encouraged comprehensive analysis of product. Easy to understand	Could have jumped to result without tool! Still focused on incremental improvements
Functional analysis (4)	4	2/3	Yes	Good way of mapping full system (product and beyond)	Structuring map proved difficult Strongly linked to current system
9 Windows (1)	1	3	Yes	Potential to integrate stakeholders	Ideas seemed unrelated to analysis

Table 5.3 Participant feedback on the eco-innovation tools from the in-house and their main strengths and weaknesses

5.5.3 Selection of the five tools for the industrial trials

Experience from the in-house trials had shown that it took around 1.5 hours to complete one tool activity and hold a feedback session. Based on an eight-hour working day, the maximum number of tools that could be completed within a one-day workshop was five. Five tools was also considered sufficient to offer the participating companies an interesting variety of tools, that emphasised different aspects and activities of eco-innovation.

The process for selecting the five tools to be taken forward to the industrial trials involved reviewing the evidence from each of the following sources:

- Feedback from the designers – the feedback forms and the associated audio data from the in-house trials were reviewed to assess the participants' perceptions of the ease of use and understanding of the tools and their opinions as to the value of the tool. This evidence is summarised in Table 5.2 in the previous section.
- Quality of the ideas generated – the outputs from each of the sessions were reviewed and (subjectively) assessed as to the novelty and the potential environmental benefits of the ideas generated.

As well as this evidence, consideration was also given to the following two factors:

- Eco-innovation inspiration - did the tool promote discussion on the drivers and benefits of eco-innovation or new approaches? Were the designers engaged and inspired by using the tool?
- The balance of the eco-innovation 'toolbox' – the eco-innovation 'toolbox' was intended to help with a range of different eco-innovation activities e.g. idea generation, problem analysis, decision making. Hence, it was important to consider what unique quality the tool contributed to the toolbox.

Before finalising the tool selection it was noted that the Ideal Final Result and Backcasting tools share the same underlying principle i.e. start at the desired outcome and work backwards. The two tools were therefore combined into a hybrid tool which was subsequently named the 'Sustainable Final Result' (SFR) tool.

At this point, based on the evidence and factors outlined above, the final five tools to be included in the toolbox for eco-innovation were selected. They were as follows: Future Scenarios, BEC Diagram, Sustainable Final Result, Eco-value and 9-Windows. The justification for the inclusion of these tools and the rejection of the remaining tools is summarised in Table 5.3.

Tool	Result	Reason
Future Scenarios	Included	Thinking about the long-term future was considered a vital activity for eco-innovation which may involve significant research and development projects. The scenarios tool was enjoyed by participants due to the creative element required to imagine interesting Future Scenarios.
BEC Diagram	Included	was amongst the easiest and quickest tools to use and required very little data or information to apply successfully.
Sustainable Final Result	Included	Both the Ideal Final Result and the Backcasting tools led to very novel product concepts being generated and could easily be combined due to the similarity of the underlying principle.
Eco-value	Included	Although there was some scepticism about the novelty of the outcomes, it promoted interesting debate about 'rebound effects' (see, for example: Hertwich, 2005) and other fundamental issues concerning sustainable production and consumption. It was also seen as a key tool in linking financial and environmental considerations in product development.
Portfolio Maps	Rejected	Significant amounts of data required on existing products to apply effectively and less thought-provoking than the Eco-value tool.
Objectives tree	Rejected	Trial participants felt that the tool offered little additional insight into the problem, particularly given the significant effort required to create the objectives tree.
Functional analysis	Rejected	Because the tool was based on analysis of the existing system the tool outputs were more incremental in nature. Furthermore, more detailed guidance was needed on how to structure the 'process-stakeholder map'.
9 Windows	Included	Trial participants felt the tool would be beneficial for integrating different stakeholders' views of a problem and was the best of the 'clarifying problems' tools.

Table 5.4 Selection of the five eco-innovation tools to take forward for the industrial trials.

5.6 Summary and Conclusions

This section has documented the development of the toolbox for eco-innovation. Having explained that the toolbox was based on existing innovation tools, Section 5.2 presented a review of tools that had been highlighted as potentially relevant for eco-innovation. Section 5.3 then reviewed the ten tools previously highlighted in terms of their relative strengths of weaknesses from an eco-innovation perspective. Section 5.4 explained how the innovation tools had been adapted for use in eco-innovation workshops. Section 5.5 detailed how the in-house testing had been conducted, the results of those workshops and the selection of the final five eco-innovation tools to be used in the industry trials. The five tools were:

- Future Scenarios
- Eco-value
- BEC Diagram
- 9 Windows
- Sustainable Final Result.

One failing of this tool review process was that QFD for the Environment was not fully reviewed, despite the fact that the use of QFD within several of the companies involved in the preliminary industrial study had previously been highlighted as a potential entry point for eco-innovation. The reason for this tool's omission was that it was considered to be more appropriate for incremental innovation than radical innovation. This is because QFD is intended to help design teams make small improvements to an existing product, but is likely to fail if applied to more radical product concepts because:

> *If no current product exists in the market that embodies at least the most primitive form of a new product, consumers have no foundation on which to formulate their opinions.(Leonard and Rayport, 1997)*

In retrospect, QFD or QFD for the Environment should perhaps have been included within the review of potential eco-innovation tools as these tools can help to improve the requirements specification formulation process and integrate environmental considerations. These are important qualities in the context of eco-innovation as several authors view the integration of environmental requirements within the requirements specification document as a key success factor for eco-design and eco-innovation (Cramer and Stevels, 1997, Olundh, 2006, Simon et al., 2000). McAloone (2002) noted that there was a lack of tools to support this activity. Olundh (2006) has made a contribution in this area by defining four alternative strategies to integrating environmental requirements. However, it is believed that these strategies would benefit from the support of a tool such as QFD for the Environment by facilitating a more systematic, quantitative analysis of the requirements.

A methodological issue which could have improved the in-house trials was that the tools could have been tested on just two product case studies as each set of participants only applied two tools each. This would still have avoided any risk of learning effects but would have helped in the evaluation of the tools, particularly in comparing the quality, quantity and type of ideas produced.

In the following chapter the activities completed with the industrial collaborators are explained and reviewed. A tool introduction process is proposed and used to customise the eco-innovation tools to the specific requirements of the companies. The effectiveness of this process is reviewed in light of the results of the tool introduction activities with the four case study companies.

6 Customising eco-innovation tools

Figure 6.1 on the following page summarises the research activities discussed within this chapter. The research activities covered in this chapter are used to answer the research questions:

'What are companies' initial responses to eco-innovation tools?' and 'Can innovation tools be customised to the eco-innovation requirements of a company, and if so, how?'. Also shown in Figure 6.1 is the process for tool customisation which is presented and explained in Section 6.1. This process was the template for the company interventions and is based on the work of Ritzén and Lindahl (2001).

Section 6.3 presents the findings from the one-day workshops and answers the first research question by providing insights into the responses of the companies to the eco-innovation tools. Section 6.4 explains how the requirements of the design team were captured through the Week 1 workshops and interviews; compares the design team requirements across the four companies; and explains how the Week 2 tool evaluation requirements were developed. Section 6.5 details the tool customisation strategy and gives detailed examples of how the tools were customised. Section 6.6 reviews the effectiveness of the tool customisations within each of the four companies before using cross-case analysis to search for more general trends. Finally, Section 6.7 summarises the conclusions from the chapter.

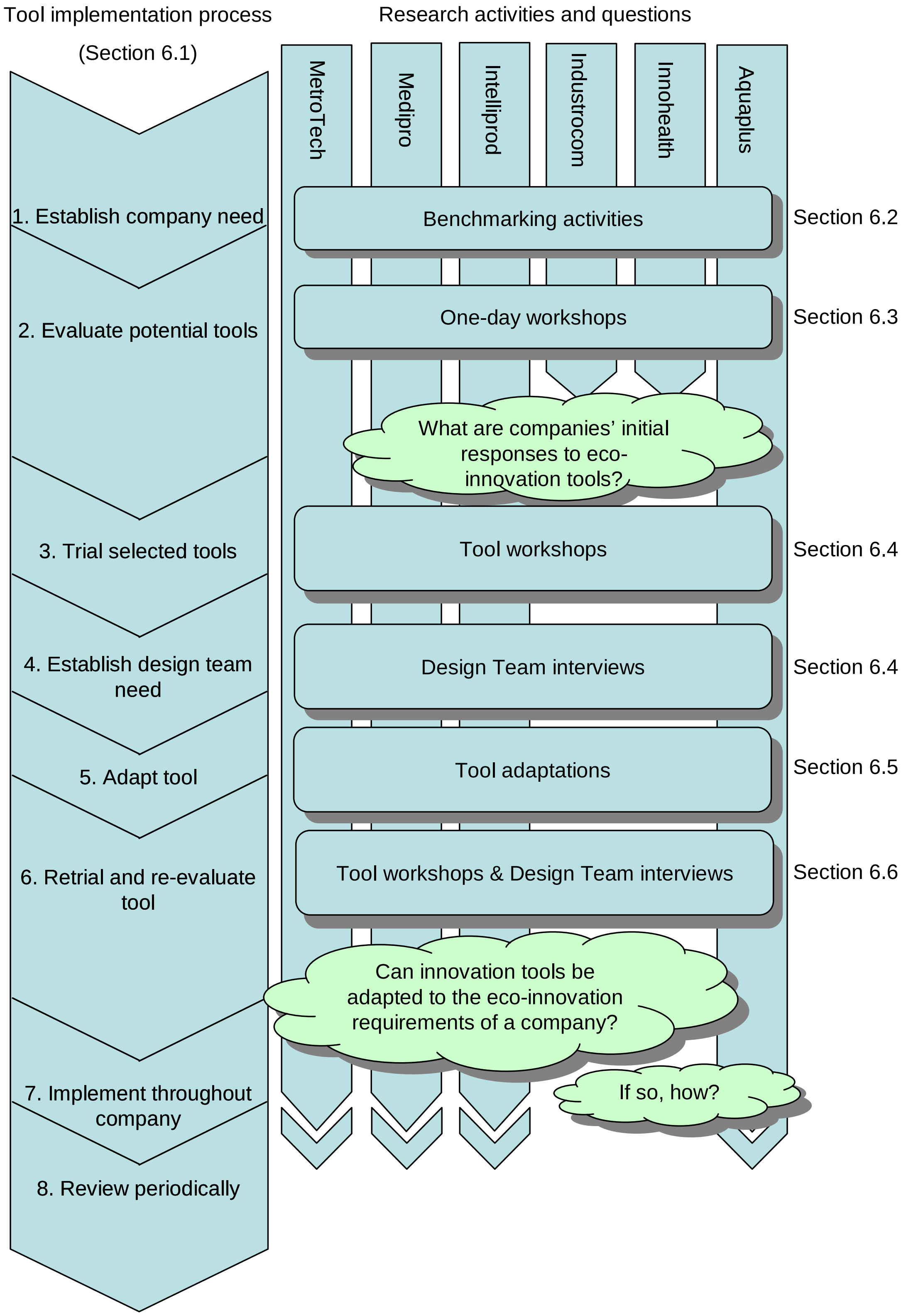

Figure 6.1: Summary of the interventions completed, the research questions and the proposed tool introduction process

6.1 Model of the tool introduction process

In this section a model of the customisation process for design tools, including eco-innovation tools, is proposed. It is described here at the beginning of the chapter as it was used as a template for the interventions within the case-study companies. In Section 6.9 the process will be reviewed in terms of its effectiveness at facilitating the introduction of new design tools into a company based on the case study evidence.

In Section 3.4.3 it was noted that Ritzén and Lindahl (2001) have previously proposed processes both for design tool selection and for introduction based upon the principles of change management. Other authors have also begun to look at the introduction of eco-design activities within an organisation from a change management perspective (Verhulst et al., 2007). It was therefore concluded that tackling the issue of eco-innovation tool introduction as a type of change management problem was likely to bring significant benefits by providing an alternative perspective on the problem and through access to the extensive body of knowledge in this area.

In Figure 6.2 a simplified tool introduction process is presented that draws upon elements of both the tool selection and tool introduction processes described by Ritzén and Lindahl (2001). The most notable influence from the work of Ritzén and Lindahl is the development of 'contextual tool criteria'. Contextual tool criteria are tool evaluation requirements that are specific to the particular situation in which a tool is being introduced. They should therefore reflect the variations in tool introduction context that exist in aspects such as product type, type of organisation, NPD process, size of company etc. The key difference in comparison with the processes described by Ritzén and Lindahl is that the current process model includes tool customisation as a key activity whereas Ritzén and Lindahl imply that the tool is used in its original 'off-the-shelf' format.

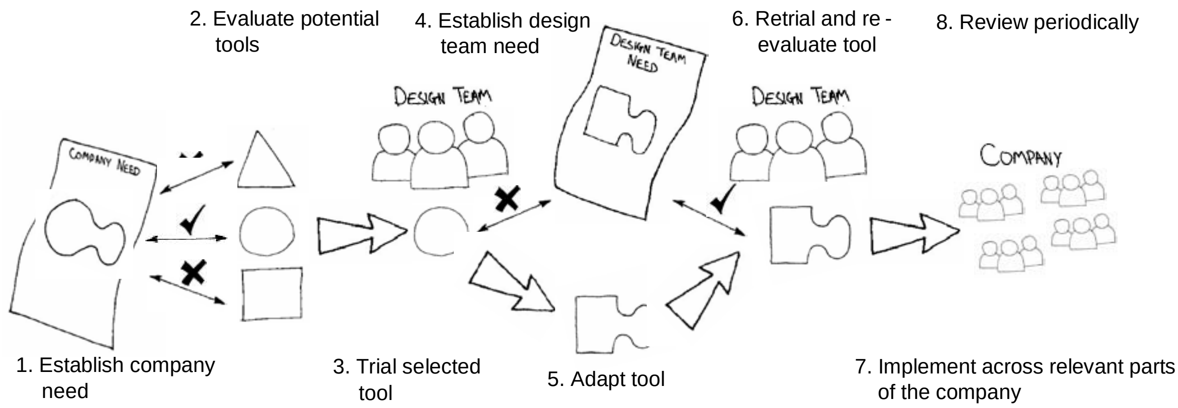

Figure 6.2: A process for the selection and introduction of eco-innovation tools

Whilst previous authors have advocated tool customisation (Boks and Pascual, 2004, Jänsch and Birkhofer, 2007, Knight and Jenkins, 2009, Luttropp and Lagerstedt, 2006) there are limitations to such an approach. Tool customisations are feasible for relatively simple, workshop-based tools – as will be seen in later sections. However, when a tool is more complex, or is implemented through third-party software, it will become more difficult to go through fast iterations of the tool which are a feature of the approach. The tool customisation process described here is therefore mainly relevant for relatively simple tools. However, given that very early stages of eco-innovation will often involve simple tools, it is suggested that this is not a significant problem.

The process can be described as follows:

1. *Establish company need* – this will be determined to a large extent by the overall company strategy, but will be influenced by other factors such as: the requirements of environmental legislation; types of tools currently used; level of innovation performance etc. The aim is to establish what the company is trying to achieve and how implementing a new tool might contribute to reaching these goals.

2. *Evaluate potential tools* – this can be achieved through short 'taster' sessions to apply a variety of potentially relevant tools. There should be significant representation from management at this stage as they must judge if any of the tools are likely to meet the company need. This activity should therefore conclude with an evaluation of the tools and the selection of one or two to take forward for in-depth trials.

3. *Trial selected tool* – tool trials should include key stakeholders in the early stages of the innovation process e.g. marketing staff, design team members etc. Input from management is less critical at this stage as the focus of the activity is for the design team to learn about the tool and to begin to highlight problem areas for the application of the tool.

4. *Establish design team needs* – individual interviews with participants from the initial tool trial should be used to gain feedback about the tool, to discuss possible tool customisations and to establish a set of requirements that reflect the needs of the design team; referred to by Ritzén and Lindahl (2001) as 'contextual tool criteria'. The requirements should be validated by the design team before being used in stage 6.

5. *Customise tool* – using both the feedback comments from the first trial and the contextual tool criteria as a guide, the tool should be customised to resolve any problematic issues and to make the tool more applicable. The initial company need should be borne in mind when making such customisations.

6. *Retrial and re-evaluate* – in order to make a fair assessment of the tool it should be applied at this stage to real, live projects. The contextual tool criteria should be used to evaluate the tool. Management input should be sought again at this stage so that they can decide whether or not to use the tool in future eco-innovation projects.

7. *Implement across relevant parts of the company* – this phase should begin with an assessment of the drivers and barriers to the introduction of the tool. Action can then be taken to reduce barriers and draw upon existing drivers before attempting to roll-out the tool across relevant parts of the company. Careful planning of the training and support requirements should also be completed and the necessary long-term funding secured before commencing the tool 'roll-out'. The term 'roll-out' refers to the implementation of the tool within other design teams. Note that in very small companies there may not be any other design teams. However, in such cases it is still necessary to plan for the support and maintenance of the tool.

8. Review periodically – once one real project has been completed with the aid of the tool, a review should be completed to assess the contribution of the tool both to the project and to the underlying company need. Any problems encountered during the application of the tool should also be noted and corrective action taken where possible. Annual reviews may be appropriate to ensure that the tool continues to satisfy the company need and to assess the on-going utilisation of the tool and also identify where new tools may be needed. N.B. This type of periodic review fell outside of the scope of the research.

6.2 Establishing the needs of the company

This section presents the findings from the benchmarking activities for each of the six participant companies. The aim of conducting the benchmarking activities was twofold: to establish what the 'company need' for eco-innovation tools was (i.e. why was the company interested in introducing eco-innovation tools); and to provide the researcher in a short space of time with a good understanding of the company's innovation and environmental activities - which they did effectively.

In sections 4.1 and 4.2 the development of the benchmarking activities and method used to score the results was detailed. Between the preliminary industrial study and the application of the benchmarking activities with the case-study companies, a number of constructs were developed to focus the analysis of the companies environmental and innovation performance, as recommended by Eisenhardt (2002). The constructs reflect theoretical issues that were believed to be relevant for explaining a company's preference for eco-innovation tools. These are summarised in Table 6.1. For each construct, the companies have been rated as showing 'poor performance', 'limited performance' or 'good performance'. These ratings were given by the researcher after reviewing the company scores from various aspects of the benchmarking activities, as shown in Figure 6.3. Note in particular that the scores from different phases of the life cycle thinking activity are separated out and used as evidence input to the 'Eco-design performance' and 'Environmental performance' constructs.

Construct	Description
Environmental ‘proactivity’	An environmentally proactive company will take actions on issues which it feels are environmentally significant or significant for customers, not just on issues for which they face imminent legislation. The company’s actions drive environmental improvements across its supply-chain.
Environmental performance	Focuses on how well the company manages the environmental aspects that are typically dealt with by environmental management systems and for which the company has a high level of control e.g. manufacturing process, packaging and distribution.
Eco-design experience	Relates to the actions the company has taken to manage the environmental aspects that are typically not dealt with by environmental management systems e.g. selection of materials, impacts during product use, product End-of-Life strategy etc.
Innovation culture	Assess the efforts a company makes to engender a culture which supports innovation.
NPD process management	Good NPD process management involves having a well-defined and documented NPD process which is widely used.
Use of design tools	Design teams should be able to draw on a range of tools to meet the demands of the design task and the use of tools should be supported and encouraged.

Table 6.1: Descriptions of the innovation and environmental performance constructs

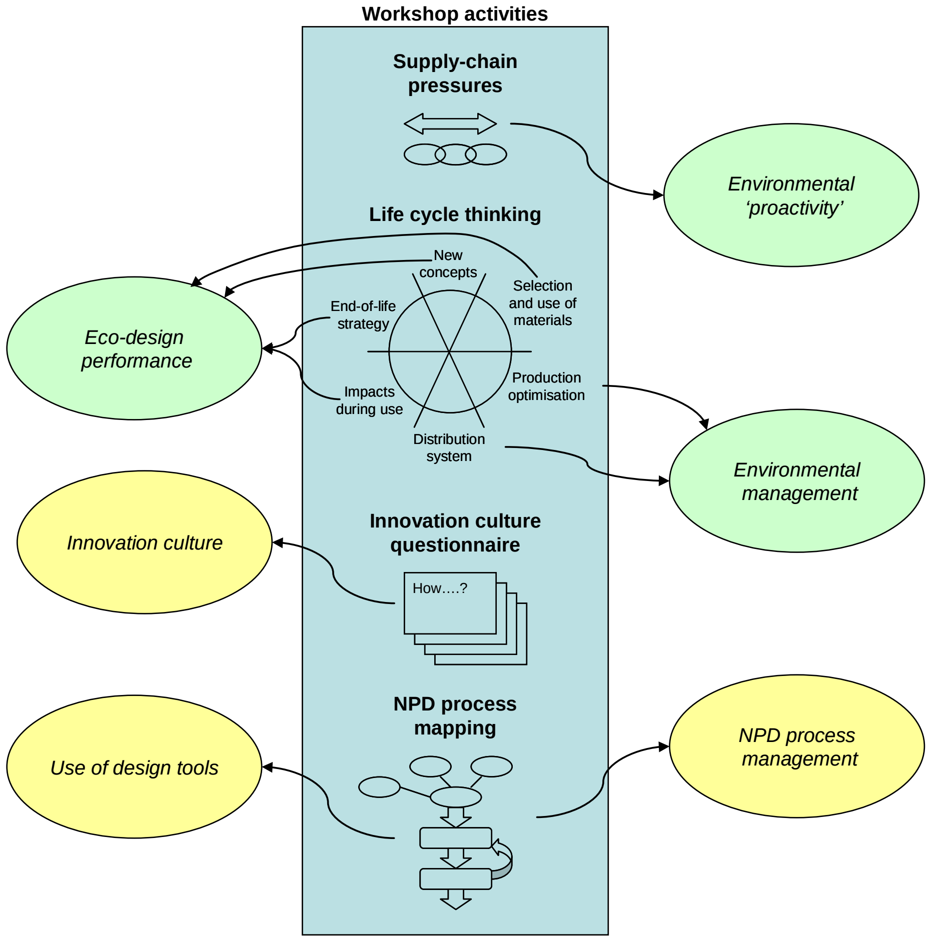

Figure 6.3: The relationship between the benchmarking activities and the environmental and innovation constructs

Before discussing the findings of the benchmarking activities, some of the limitations of this part of the study should be noted. First, because the activities were based on self-reported measures, there is scope for bias within the results i.e. because performing well in innovation and environmental activities is generally considered to be a positive characteristic the respondents may have claimed (or genuinely believed) that they were better than they actually were. The measure taken to reduce this type of bias was to ask for evidence to back-up claims. In certain cases where there was a strong belief that the respondent was providing biased responses (whether intentionally or not), triangulation of sources was used to further corroborate or falsify the original claims.

Turning now to the results, from Table 6.2 it is clear that the participating companies had significant differences in terms of their innovation and environmental performance. On one hand there was Medipro that had a long track record of engaging in environmental management and eco-design whilst also having significant resources and capability for innovation. On the other hand there were companies such as Industrocom and Innohealth who were much smaller companies and had no experience of eco-design.

Company	Environmental proactivity	Environmental management	Eco-design experience	Innovation culture	NPD process	Use of design tools
MetroTech	0	+	0	+	+	+
Medipro	++	++	++	++	++	++
Intelliprod	+	+	+	++	++	0
Industrocom	0	+	0	0	+	+
Innohealth	0	0	0	0	0	++
Aquaplus	+	++	+	+	+	+

Key: 0 - Poor performance,
+ - Limited performance
++ - Good performance

Table 6.2: Summary of the results of the benchmarking activities

From these results two main assumptions emerged regarding the types of tools and tool customisations that each of the companies would need:

- Companies that scored well on the innovation benchmarks but poorly on the environmental benchmarks would need tools that could improve their environmental knowledge.
- Conversely, companies that scored well on the environmental benchmarks but poorly on the innovation benchmarks would need tools that could stretch their innovation performance.

These assumptions are represented schematically in Figure 6.4. It was also assumed that companies that showed well balanced innovation and environmental performance would benefit from any tool that could stretch their eco-innovation performance. It was hoped that selecting and customising tools based on these assumptions would help the companies to become expert eco-innovators. The validity of these assumptions and the specific tool customisation decisions that they affected are discussed later in this chapter.

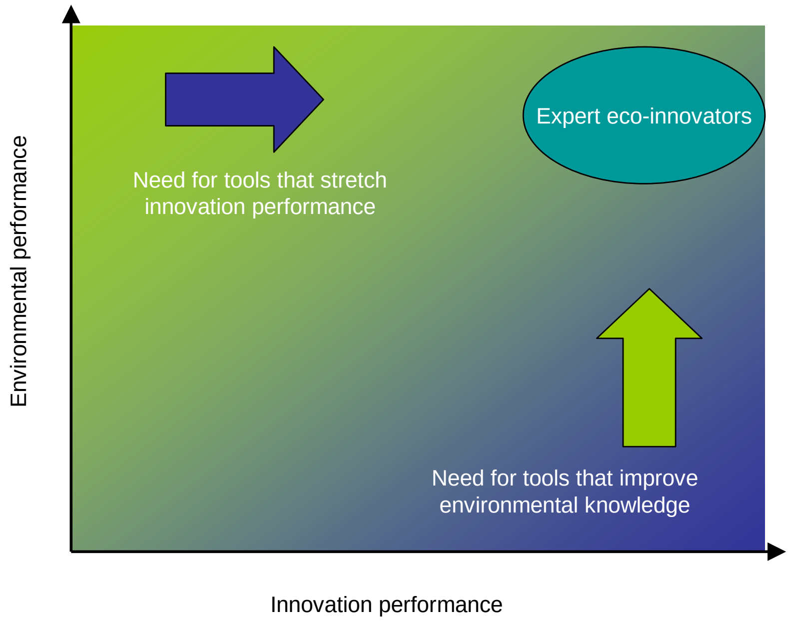

Figure 6.4: Assumptions about the types of eco-innovation tools that a company would need based on their innovation and environmental performance

Given the variation amongst the companies in their existing innovation and environmental performance it is not surprising that there was a similarly wide range of reasons for companies deciding to engage in eco-innovation. Having an understanding of the reasons why the companies had decided to engage in eco-innovation activities was considered to be important as it was believed that this would influence how the companies viewed the tools and what types of customisation would be appropriate. With this in mind, Table 6.3 provides a summary of the primary and secondary 'needs' of the companies for improving their environmental performance and engaging in eco-innovation. The table is based on evidence from the benchmarking activities and field notes made during visits to the companies.

Company	Primary factors	Secondary factors
MetroTech	Desire to improve front end of innovation activities and stimulate innovation within the company. Having invested significant time and effort in voluntarily becoming RoHS compliant for very little benefit, MetroTech wanted to explore how they could gain a competitive advantage from improved environmental performance.	Pressure from city analysts to improve the company's environmental credentials.
Medipro	Protect and enhance corporate brand value. Industry-wide move to reduce costs following major changes to financing within US healthcare system.	Long product development cycles and low-tolerance for technical risk means that changes arising from environmental legislation must be 'mastered' well ahead of schedule.

Intelliprod	Seeking to differentiate brand through environmental sustainability. Wanting to stimulate innovation to move out of low-margin market segments.	The possibility of reducing the cost of compliance with WEEE, RoHS and EuP Directives.
Industrocom	US Corporate owners planning to introduce a Key Performance Indicator (KPI) on environmental sustainability.	Interested in tools for cost reduction.
Innohealth	Developing a disruptive innovation and keen to explore possible environmental benefits compared to incumbent technology.	Good culture of innovation and always open to new innovation tools.
Aquaplus	Pressure from retailers to deliver products with good environmental credentials without increased cost. Legislation - Code for Sustainable Homes resulting in more demand for low energy and low water usage products from house builders. Susceptible to changes in materials prices e.g. brass, copper, steel.	US Corporate owners planning to introduce a Key Performance Indicator (KPI) on environmental sustainability.

Table 6.3: Summary of the 'needs' of the companies for improving their environmental performance and engaging in eco-innovation

It should be noted that some of the needs listed in Table 6.3 are more general drivers for improving environmental performance rather that being specific 'needs' for engaging in eco-innovation. This is because in practice it is very difficult to separate out the specific needs for eco-innovation from the more general drivers of environmental performance.

In searching for patterns across the cases five themes emerge as motivating factors for improving environmental performance and engaging in eco-innovation activities: corporate brand protection and enhancement, product differentiation, improving innovation performance; legislative compliance, and cost reduction.

Corporate brand protection and enhancement

This was found to be a significant reason for engaging in eco-innovation within for four of the six cases. Interestingly, this was not in response to direct environmental pressures from customers at a company level. It was instead at the corporate level that these pressures were being felt. Corporate management was passing down these pressures to the company level through mechanisms such as Key Performance Indicators (KPIs) for environmental performance. It is suggested that this is because these types of publicly-listed corporations currently view environmental performance as both a major risk and an opportunity. It is a risk in that poor environmental performance is likely to draw attention from Non-Governmental Organisations (NGOs) such as Greenpeace and Friends of the Earth who publish reports on the environmental performance of large electronics companies (Greenpeace, 2009). This type of negative press could have a significant impact on company sales and share value.

Conversely, environmental performance is an opportunity to differentiate the organisation and increase brand value – an idea supported by recent independent research (Mahler et al., 2009). This discrepancy between corporate and business-level objectives leads to situations such as that witnessed at MediPro where there was strong support for environmental performance from the corporate Directors and the corporate-level marketing function, but less interest at the company-level from the marketing function who had made it clear that they did not feel it provided a marketing advantage.

Product differentiation

The most significant example of product differentiation as a motivating factor was Intelliprod, who had undergone a strategy review some 12 months prior to participating in the research and had decided to use environmental sustainability as their Unique Value Proposition (UVP) within the crowded and competitive electrical domestic products industry. This had led to the development of a range of eco-branded products that offered reduced energy consumption compared to competitor products.

Aquaplus also engaged in marketing particular products or product features as being ‘eco’. This was at the request of retailers and home builders. However, neither of these markets were willing to accept price increases.

Improved innovation performance

Within MetroTech, ‘buy-in’ to the research was gained by presenting the research as an opportunity to improve front end of innovation activities. In particular, it was felt that some of the eco-innovation tools could be used to promote a better understanding of user requirements – which was a recognised area of weakness within the company.

Intelliprod were also interested in the potential of eco-innovation tools to help improve innovation performance. Their particular problem was that, in meeting the demands from retailers for regular incremental innovations, their innovation funnel had become devoid of any radical innovation projects. Intelliprod therefore felt that the eco-innovation tools could be applied to stimulate some more fundamental research projects, hopefully leading to step-change innovations and genuinely new products.

Legislative compliance

Early compliance with environmental legislation has often been highlighted as a key benefit of proactively adopting eco-design principles and tools (O'Hare et al. 2007). However, for eco-innovation we might expect legislative compliance to be a less important driver as policy measures generally aim to improve the performance of the laggards and heaviest polluters rather than trying to significantly advance the leading edge technology.

For instance, the recently introduced Energy-using Products Directive requires manufacturers of affected products (such as electric motors, water heaters, lighting products etc) to meet product performance targets for things such as standby energy consumption or thermal efficiency, that are based on the ‘Best Available Technique Not Entailing Excessive Cost’ (BATNEC). Hence, the targets set are, by their nature, able to be met using existing, commercially-viable technology, and as such they set no requirement or incentive for companies to go beyond current best-practice and invest in eco-innovation. However, in the case of Medipro legislative compliance was a contributing factor for engaging in eco-innovation because of the long duration of product development cycles (several years) and a strong risk-management culture. This combination of factors meant that any technical changes driven by legislation had to be well ‘mastered’ before being introduced into the product and before the any legal obligation to do so. In addition, it was discovered that the company had a history of successfully lobbying policy makers to influence legislation such that Medipro were well-positioned to comply with requirements. It could be argued that this company was engaging with the eco-innovation tools for the purposes of eco-design (as opposed to eco-innovation), just on a longer than usual time-line.

Cost reduction

There was an interesting range of views encountered amongst participants in the various companies with regard to impact of eco-innovation on product costs. Within Medipro, the general belief was that eco-innovation could lead to reductions in manufacturing or running costs but this can be explained by the fact that they have long-history of pursuing environmental performance improvement and have produced many, well-publicised examples of eco-design leading to cost reduction benefits. In contrast, many of the design team at MetroTech expressed the opinion that eco-innovation would inevitably lead to increases in product cost. However this may well be related to their recent experiences of complying with the RoHS Directive which had been completed at significant effort and cost but with apparently very little commercial benefit. Overall, four out of the six companies cited cost reduction as a factor in the decision to pursue eco-innovation activities. This finding is consistent with insights from a recent study by Rangaswami and Simmons (2008) who found that champions of eco-innovation are under increasing pressure to justify action on environmental performance through Return On Investment (ROI) calculations. This may be possible in the case of simple materials-cost savings or production-energy-cost savings, but currently we lack appropriate requirements when faced with more complex cases e.g. ‘How do you put a dollar value on the brand reputation benefit associated with being the first company in our industry to introduce a product based on ‘xyz’ technology?’ Furthermore, it is very difficult to evaluate the environmental benefits associated with such actions which would help to evaluate the effectiveness of dollars invested from an environmental perspective. These issues merit further attention.

Having highlighted some of the strategic needs that the companies were seeking to address by engaging in eco-innovation, it was hoped that these needs would help to guide for the rest of the tool customisation process. Essentially the problem was that these ‘needs’ expressed *why* companies wanted to engage in eco-innovation but they did not provide any insight into exactly *what* the companies wanted the tools to do or *how* they should do it. This was a flaw in the tool customisation process. In Section 6.6.7 a possible solution to this problem is discussed. Despite this, understanding why companies wanted to engage in eco-innovation was found to be an important part of the process because by discussing these needs with the research coordinator, the researcher and the research coordinator were able to develop a more persuasive business case when seeking approval for participation in the research from senior management. This was particularly key in the case of MetroTech where the ‘pitch’ was altered to focus on the potential innovation benefits of using the tools rather than the environmental benefits.

In summary, this section has presented the findings from the benchmarking activities which were conducted to develop a better understanding of the needs of the company for eco-innovation tools. The results of the main activities led to two working assumptions: that companies that scored well on the innovation benchmarks but poorly on the environmental benchmarks would need tools that could improve their environmental knowledge; and vice versa. When analysing the reasons cited by companies for engaging in eco-innovation five themes were noted: corporate brand protection and enhancement, product differentiation, improving innovation performance; legislative compliance, and cost reduction. This analysis helped to understand *why* companies had decided to engage in eco-innovation and proved important when presenting the business case for continued participation in the research. However, it did not help to understand *what* the companies need eco-innovation tools to do or *how* they should do it.

6.3 Evaluating the potential tools

The tool evaluation phase of the tool introduction process was completed by conducting one-day workshops with each of the case-study companies. The objectives of the workshops were:

- to provide the company with an opportunity to learn about the five eco-innovation tools and evaluate their potential value to the company;
- to assess the design team’s initial reaction to the eco-innovation tools.

Section 6.3.1 describes the protocol used for each of the one-day workshops and Section 6.3.2 presents the results and conclusions from this part of the study.

6.3.1 Methodology for the one-day workshops

The one-day workshops were completed with individual companies at their own premises. As the companies signed-up to participate in the research at different times, the workshops were spread over a seven month period. The main contact person within each of the companies was responsible for inviting staff to participate in the workshops. They were asked to invite 6-12 participants including representatives from Senior Management, Engineering, Manufacturing, Quality, Environment, Health & Safety and Marketing. Table 6.4 shows that in practice none of the companies managed to include representatives from all of these functions, with Marketing and Manufacturing being particularly poorly represented.

Company	Number of participants	Business functions represented	Type of tasks
Metrotech	7	Senior Management Engineering Quality	Theoretical case studies
Medipro	Day 1 = 11 Day 2 = 9	Engineering Quality Environment, Health & Safety	Company-specific issues
Intelliprod	8	Senior Management Engineering Marketing	Theoretical case studies
Industrocom	6	Engineering Quality Environment, Health & Safety Manufacturing	Theoretical case studies
Innohealth	3	Senior Management Engineering Marketing	Theoretical case studies
Aquaplus	9	Senior Management Engineering Environment, Health & Safety	Theoretical case studies

Table 6.4: Summary of the one-day workshop participants and issues tackled

The format for the day was consistent across five of the companies but within Medipro a number of changes were made. First, the ‘day’ was split over two days. Of the 18 unique participants, only two were present for both days. This was done to reduce the time demand on the participants. Secondly, to further maximise the value of the day the company requested that the tools be applied to real, company-specific issues rather than the pre-prepared case studies used with the other companies. Thirdly, the BEC Diagram tool was not presented or evaluated because the company had already introduced a similar tool as part of their eco-design policy. Each of these changes will have had some limiting effect on the comparability of the results with those from the other cases.

Obviously, as the BEC Diagram tool was not tested, no comparisons are possible. The impact of splitting the activities over two days and using different participants was not considered to have a significant effect on the comparability of the results because the two cohorts had very similar profiles. It will also be noted that the Innohealth workshop was attended by just three people. The effect of this was that the day progressed quicker than at other companies. However, as this group were still representative of the wider company, it was concluded that this did not significantly affect the results of the activity.

The programme for the one-day workshops generally started with an overview of the day, an introduction discussing ‘what is eco-innovation?’ and ‘why is our company interested in eco-innovation?’, including a short ice-breaker exercise. Following this, an introduction was given to the first tool lasting 10-15 minutes. The participants were then set a task to complete using the eco-innovation tool. The tasks were based on theoretical case studies of commonly used products. Table 6.5 provides an outline of the tasks presented to the group for each of the five tools. Different tasks were set for each of the tools because after the group had applied one tool to a task, when applying subsequent tools to the same task they might have focused on the ideas they had generated previously. Alternatively they may have censored themselves from mentioning ideas that had been discussed before. It was concluded that these type of effects were more likely to be a problem than the potential decrease in ‘comparability’ between tools due to using tasks.

For the activities the participants were separated into two or three smaller groups as training experts suggest that small group activities can help to maintain interest and increase participation (Jolles, 2005). Both groups applied the same tool to the same task at the same time. A summary of the task for each tool is provided in Table 6.5.

Tool	Task
9 Windows	Generate ideas for eco-innovation projects for a mobile phone producer to tackle the problem of “energy use of mobile phones during the use-phase.”
Eco-value	Use an Eco-value approach to evaluate the range of eco-innovation strategies that a kitchen appliance producer could apply to toasters. Describe the main product features that would need to be included in a toaster for the following consumer types: ‘Price buyer’, ‘Special-feature buyer’, ‘Experience-quality buyer’.
Future Scenarios	Use the Future Scenarios method to search for new product opportunities for an office furniture producer that will help to significantly reduce the environmental impact of working in offices.
Business-Environment-Customer Diagram	Use the BEC Diagram to help a power tools producer develop some new eco-innovation project ideas for a cordless power drill.
Sustainable Final Result	Use the Sustainable Final Result tool to help a white goods producer reassess the activity of ‘washing dishes’.

Table 6.5: Summary of the tasks set for the one-day workshops

After 30-60 minutes of working on the task, one member from each of the groups was asked to present the outcomes of their application of the tool back to the wider group. This allowed for the sharing of lessons learnt between the groups.

After the outcomes had been presented and discussed, the group was asked to complete a feedback form. The form consisted of the following questions (and response options in brackets):

- *How easy was it to understand the principle of the tool?*
  (Score from 1 ‘very difficult’ to 5 ‘very easy’, plus room for comments)
- *How easy was it to apply the tool?*
  (Score from 1 ‘very difficult’ to 5 ‘very easy’, plus room for comments)
- *Has any new thinking come out of the use of this tool?*
  (‘Yes’ or ‘No’, plus room for comments)
- *What did you not like about the tool?*
  (Box for comments)
- *Any other comments?*
  (Box for comments)

One feedback form was completed by the whole group based on the majority view of the group. This format forced participants to discuss the strengths and weaknesses of the tool which led to more in-depth debate. An audio recording of both the activity sessions and the feedback were made to allow further analysis and clarification.

This process of introducing a tool, applying it to a task and completing a feedback form was completed for each of the tools. The final activity completed at the end of each was generating a ranking of the tools in order of their potential value to the company. This was done by providing the group with a very brief reminder of each of the tools and allowing a brief discussion before asking for the rankings. In the following section the rankings of the tools and the feedback obtained are analysed and discussed.

6.3.2 Findings from the one-day workshop

This section considers the results from the one-day workshop and attempts to answer the question ‘What are companies’ initial reactions to eco-innovation tools?’.

Figures 6.5 to 6.9 compare the feedback scores given by the companies for each of the five tools introduced during the one-day workshop (Medipro did not test the BEC Diagram tool as they had already introduced a similar tool). The two feedback questions for which a quantitative score was given were: ‘How easy was it to understand the principle of the tool?’, and ‘How easy was it to apply the tool?’.

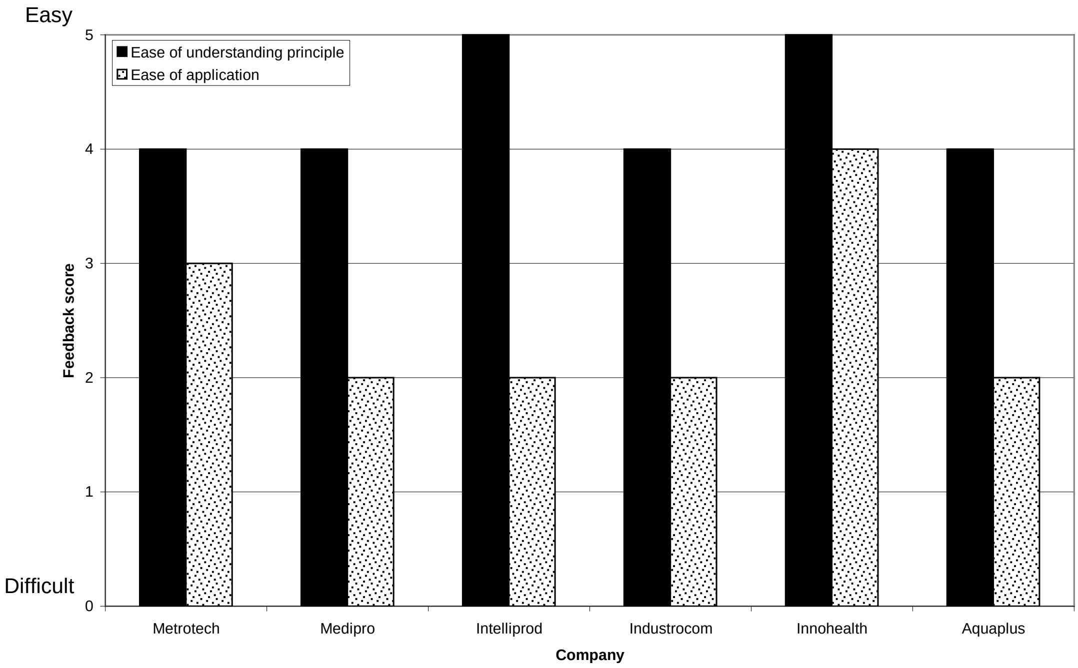

Figure 6.5: Feedback scores from the one-day workshop for the 9 Windows tool

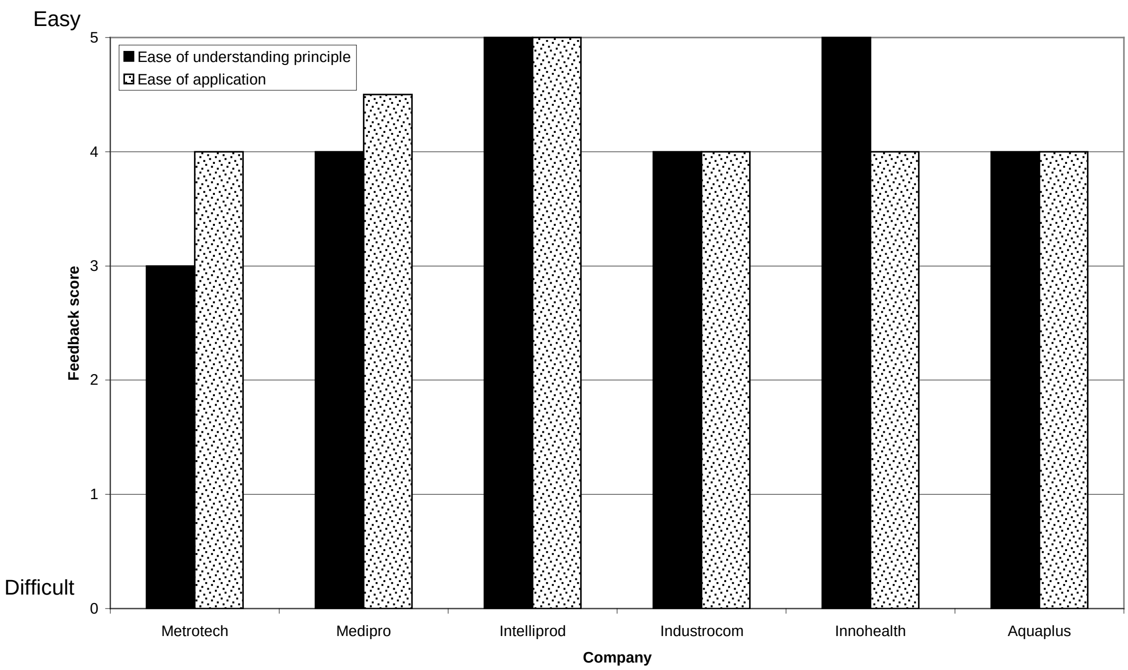

Figure 6.6: Feedback scores from the one-day workshop for the Future Scenarios tool

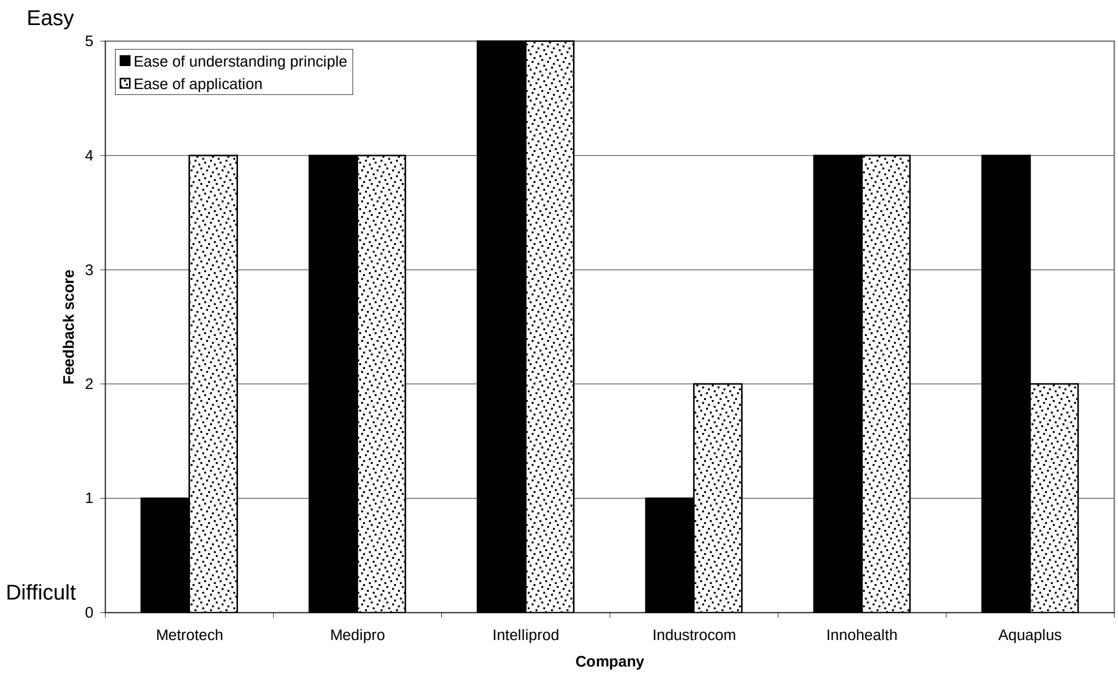

Figure 6.7: Feedback scores from the one-day workshop for the Eco-value tool

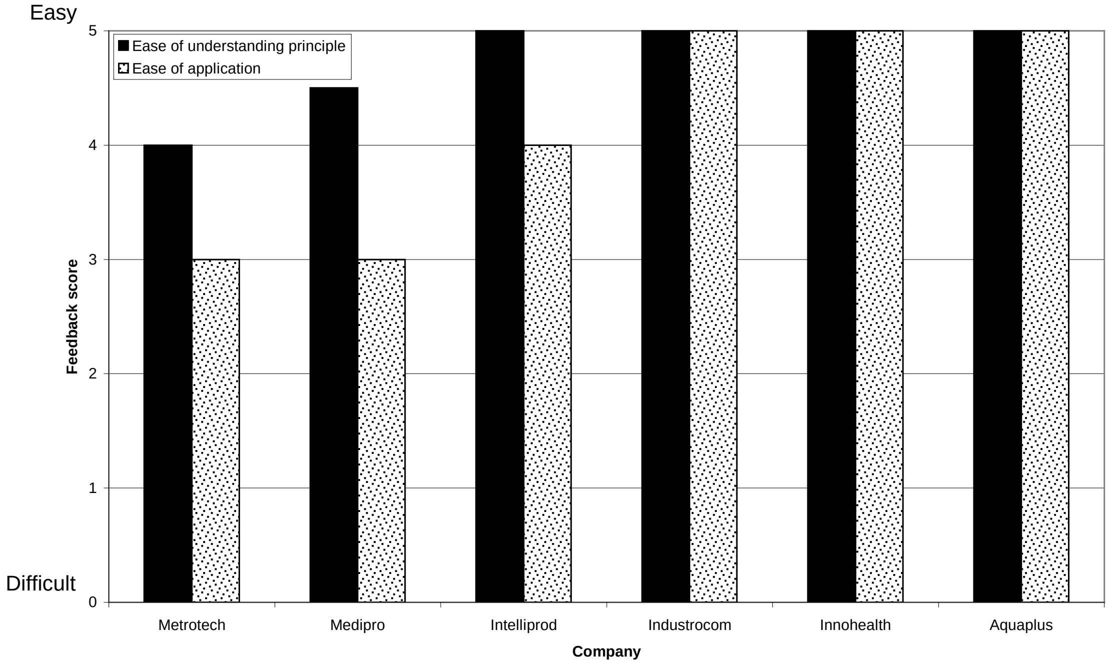

Figure 6.8: Feedback scores from the one-day workshop for the SFR tool

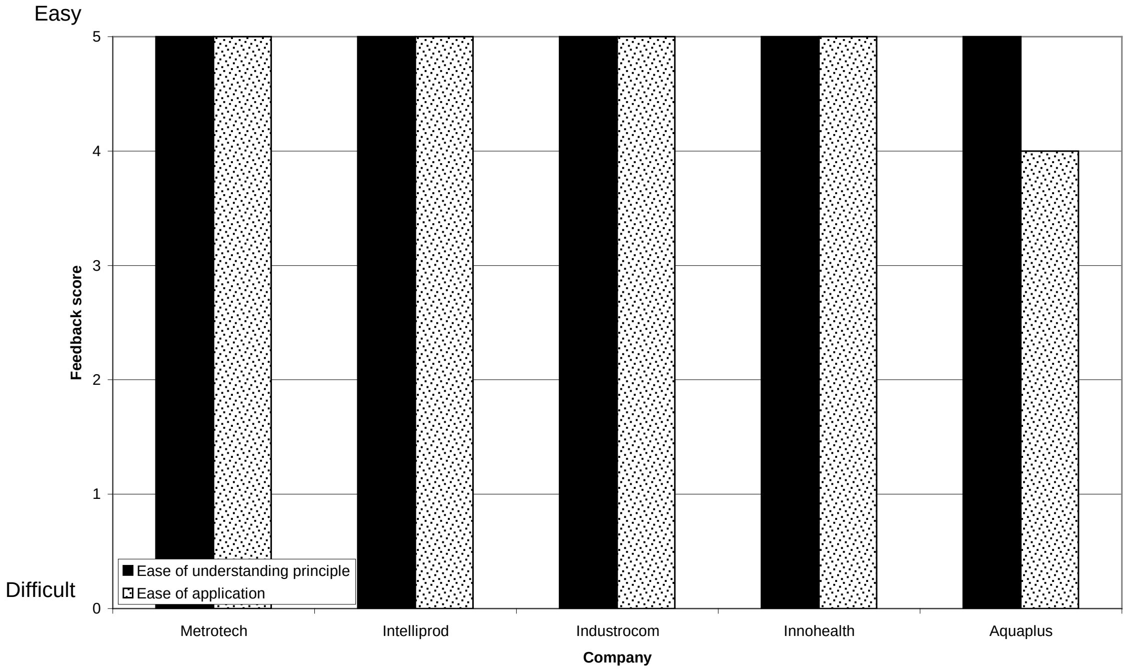

Figure 6.9: Feedback scores from the one-day workshop for the BEC Diagram tool

A number of points can be made about Figure 6.5 to 6.9. First, all of the companies found the 9 Windows tool simple to understand but relatively difficult to apply. The qualitative comments suggested that the main problems in applying the tool were understanding the different 'systems levels' and agreeing on which window a certain issue belonged in. However, five out of the six companies felt that it had generated some new thinking.

The Eco-value tool caused the widest variation in scores between companies with some companies finding it easy to understand but difficult to apply and other companies finding the opposite. The qualitative comments indicated that there were concerns that the Eco-value equation did not appear to promote a more sustainable approach and that the Eco-value of a product would not be constant over time. Some comments also suggested that the link between the Eco-value formula and the task completed was not clear.

The easiest tools to both understand and apply were the BEC Diagram followed by the SFR tool. For the BEC Diagram, this was due to the visual nature of the tool whereas for the SFR tool the ease was attributed to the simplicity of the overall principle and the step-by-step guidance from the 'structured thinking questions'.

The scoring of both Intelliprod and Innohealth suggests that they found the tools easier to use and understand than the other companies. This is understandable in the case of Innohealth as from the benchmarking study they were showed 'very good performance' in the use of design tools. However, Intelliprod had been found to have very little experience of using design tools. This anomaly may simply have been due to the fact that this particular group had a different understanding of what was 'easy' compared to the other groups. It could also have been that the group were trying to impress either the researcher of the Innovation Director of the company who participated in the workshop.

Moving on, Table 6.6 presents the overall tool rankings from each of the six companies. The 'mean rank' column is used to sort the order of the tools and is intended to give an indication of the 'popularity' of the tools. The greyed table cells indicate the tools that the company subsequently chose to trial in the two-week tool introduction studies (Industrocom and Innohealth did not participate in the tool introduction studies, as is explained at the beginning of Section 6.4).

Tool	**Company**						**Mean rank**
	MetroTech	Medipro	Intelliprod	Industrocom	Innohealth	Aquaplus	
BEC Diagram	1	-	3	1	3	2	2.0
SFR	4	1	1	2	4	1	2.2
9 Windows	2	2	2	4	1	4	2.5
Future Scenarios	3	4	4	3	2	3	3.2
Eco-value	5	2	5	5	5	5	4.5

Table 6.6: Overall tool rankings from the one-day workshops for each of the companies

From Table 6.6, the following issues were noted:

- The most popular tools based on the final ranking by each company were the BEC Diagram and the Sustainable Final Result. As noted previously, these two tools were also found to be the easiest to understand and apply and hence it would seem that their popularity is due to this.
- Future Scenarios was the third most popular tool although the comments suggested that the companies did not like the subjective approach to assessing the importance of particular drivers. It was also felt that this was a more strategy-focused tool the participants and as such it would be applied by senior management rather than engineering or marketing staff.
- The rankings of the companies were generally fairly consistent with two notable exceptions. Medipro liked the Eco-value tool (ranked 2nd compared with 5th ranked for the rest of the companies); and Innohealth liked the 9 Windows tools (1st ranked tool and found it easy to apply). This is perhaps because the Eco-value tool requires a good understanding of LCA and Medipro were the only company to regularly use LCA. Similarly, the 9 Windows tool was considered to be a harder innovation tool to apply in

general but Innohealth have previously had training on TRIZ tools, including the 9 Windows tool.

Through the one-day workshops some specific insights have been gained into the initial reactions of the companies to the eco-innovation tools. A number of general conclusions can also be drawn. First, staff from operational levels of the organisation felt that, as a strategic tool, Future Scenarios was not relevant for them. This view was reinforced by findings from the tool introduction studies which are discussed later in this chapter. The intention of including this type of strategic tool within the eco-innovation toolbox had been to allow operational-level staff to provide useful input into the formulation of a company's product and business strategies. However, the evidence from this research suggests that the formulation of a company's product and business strategies remains the preserve of senior management. The implication for developers of eco-innovation tools is that strategic-level tools should be designed for, and tested with, senior management staff.

Secondly, companies tend to prefer eco-innovation tools that are easy to understand and apply. This finding is in no way surprising but the more subtle conclusion from the comments and discussions within the one-day workshops was that the companies would not have elected to use an eco-innovation tool that required a significant amount of effort to learn or apply. This issue is discussed further in the later sections.

Finally, a number of participants commented that they found it very difficult to evaluate the tools when they were not applying them to their own products (with the exception of Medipro). This reaffirms the importance of testing tools within an industrial setting and in as 'natural' a context as possible (Eckert et al., 2004). The one-day workshops could therefore have been improved from a methodological point of view by allowing all the companies to apply the tools to real company-specific issues, as was done by Medipro.

This section has considered the question 'What are companies' initial reactions to eco-innovation tools?'. This question has led to some insight into how design teams react to eco-innovation tools, what type of tools companies prefer and why. In the following sections the activities completed during the tool introduction studies are discussed.

6.4 Establishing the design team needs

Having evaluated the potential tools and selected one or two tools to take forward, the next research activity was the 'tool introduction study'. Unfortunately, Industrocom and Innohealth were not able to participate in the tool introduction studies. This was apparently due to a lack of senior management support at Industrocom and a significant business restructuring in the case of Innohealth.

A tool introduction study was undertaken in each of the four remaining companies. The studies involved the researcher spending two weeks embedded within the company. Each study was split into two phases: ‘Week 1’, described in the following section; and ‘Week 2’, described in Section 6.6. In the first case at MetroTech the two weeks were completed back to back but it was found that this offered little time to analyse the results of the Week 1 activities and make relevant tool customisations. Hence in subsequent cases a gap of two-three weeks was left between the Week 1 and Week 2 activities. During the tool introduction studies the researcher sat in the design offices of the company being studied. This may have helped to reduce possible researcher effects, as noted in Section 3.5.3.

The aim of the Week 1 activities was to establish what requirements the design teams had of the eco-innovation tools. This was done by introducing the selected tools to the design team through workshop activities. These were followed-up with individual interviews with members of the design team which aimed to understand their requirements of the tools whilst also gaining feedback about the tools.

Section 6.4.1 provides details of the workshop activities and interviews completed during the Week 1 of the tool introduction studies. Section 6.4.2 presents a cross-case analysis of the requirements of the eco-innovation tools described by the design teams. Finally, Section 6.4.3 describes the procedure used to create the feedback requirements, which were subsequently used to evaluate the tools during the week two activities.

6.4.1 Methodology for the Week 1 activities

At the start of the week a series of workshops were organised to introduce the selected eco-innovation tools to the design team. The research coordinator within the company was responsible for inviting design team members to participate in the workshops. As with the one-day workshops, the research coordinator was asked to invite staff from a variety of business functions. The group size varied from four (Medipro) to ten (Aquaplus) and the Engineering function was once again the most commonly represented of the company functions.

The general format for the workshops was: introduction to the research; introduction to the tool; activity using the tool; present outcomes and sum-up. In most workshops one tool was introduced except at Intelliprod were both the 9 Windows and SFR tools were completed in each of the workshops. No group feedback was collected for any of the tools (although audio recordings were made). Instead interviews were held with a representative sample of individual participants from each workshop.

The interviews were conducted some at some point between 24 and 48 hours after the workshop. This allowed the interviewees some time to reflect on their experience without leaving such a long gap that they forgot what they had done. The interviews began with a short description of the aim of the interview. The researcher’s definition of a ‘design tool’ was read to the interviewee and they were asked if they happy with their understanding of what a design tool is. The first question was, ‘What design tools do you currently use in your work?’. This was primarily an ‘ice-breaker’ question but also provided some insight into the interviewee’s experience of using tools and their understanding of what constitutes a design tool. After this, the interviewees were introduced to a number of generic design-tool requirements or criteria, listed below, which were adapted from the work of Lindahl (2005).

- *Time efficient* - The time from start to finish should be short, including time for data collection or preparation.
- *Early phases* - The tool must be applicable during the early stages of the New Product Development process.
- *Low quality data* - During the early stages of product development often only qualitative or 'ball park' quantitative data are available. The tool must be able to deal with these types of data.
- *Life-cycle perspective* - The method should consider all phases of the product life cycle: materials extraction, production, distribution, use, disposal.
- *Marketing aspects* - The tool must encourage the consideration of marketing aspects.
- *Integration* – The tool should integrate effectively with the NPD process.
- *Multi-functional team* - The tool must support working in a multi-functional team and promote the exchange of information between different organisational units.

For each criterion, the interviewee was asked how important this criterion was for eco-innovation tools.

A five-point scale was used to score the tools tested and the participants were asked to comment on their scores in order to encourage more open discussion of their requirements. They were then asked to rate the performance of the tool against each of the criteria. In responding, the interviewees were asked to rate the importance of the requirement on a scale from one 'unimportant', to five 'critical'. The interviewees were also asked to rate the performance of the eco-innovation tool or tools that they had used in the workshop. Again a five-point scale was used ranging from one - 'does not meet this criterion' - through to five - 'meets this criterion entirely'. When rating both the importance of the criteria and the performance of the tool, the interviewees were asked to explain the reasoning for the score they provided.

6.4.2 Initial workshops and design team interviews

Table 6.7 summarises the workshop activities and number of interviews completed within the case study companies within the first week of the tool introduction studies. As none of the case-study companies elected to trial the Eco-value or Future Scenarios tools they are not shown. The tasks used for the Week 1 workshops were theoretical tasks (the same as previously used in the one-day workshops) except in the case of Aquaplus. They had requested that they work on real but general issues in the Week 1 workshops as they felt that they had struggled to evaluate the potential usefulness of the eco-innovation tools during the one-day workshop because the tasks were theoretical and not related to their own products. The ‘Interviews completed’ column lists the total number of interviews completed with design team members who had participated in one or more of the workshops. In this same column, the figure in brackets the number of those interviews that were transcribed and coded in the manner described in Section 2.5.2.

Company	**9 Windows**	**Sustainable Final Result**	**BEC Diagram**	**Interviews (transcribed and coded)**
MetroTech	-	-	1 Workshop, theoretical task -	3 (3)
Medipro	1 Workshop, theoretical task	-	-	3 (2)
Intelliprod	3 Workshops, theoretical tasks	3 workshops, theoretical tasks	-	5 (3)
Aquaplus	1 Workshop, real, general tasks	-	2 Workshops, real, general tasks	7 (4)

Table 6.7: Summary of the Week 1 workshops and interviews completed

A number of general issues were raised during the completion of the tool feedback interviews. First, whilst it was stressed to interviewees that they were giving feedback on the tool and on the general importance of the requirements for eco-innovation tools separately, it seemed that some of the answers they gave may have been influenced by the particular tools that they had already been introduced to. e.g. It might have been that participants who had applied the BEC Diagram tool - which requires very little detailed information - placed less emphasis on the ‘use of low quality data’ requirement because they assumed that all eco-innovation tools function without very detailed information.

Secondly, in the original tool feedback form two oversights occurred: no requirement was included for the ‘quality of the outputs’ from the tools; and the requirement for ‘integration with NPD process’ was included in the feedback form for MetroTech but was then accidentally removed from the feedback form at the remaining companies. The former issue was noted during the Week 2 workshops at MetroTech as when the participants were introduced to the tool feedback form they immediately and unanimously requested that a criterion for quality of outputs be included (which was done with immediate effect). It was subsequently decided not to change the feedback form as the form included an ‘any additional criteria?’ section that provided participants the opportunity to discuss any other key criteria they had of eco-innovation that had not been raised. The other issue concerning the 'integration' requirement was not noted until after the Medipro case study had already been completed. It was therefore decided to once again leave the feedback form in its original state as participants could discuss the topic under the 'any additional requirements?' section if necessary.

6.4.3 Creation of the Week 2 tool requirements

The main outputs from the Week 1 interviews were feedback about the eco-innovation tools and feedback about the relative importance of the tool requirements. How the tool feedback was used to inform the tool customisations is described in the next section. In this section the process of developing an customised set of eco-innovation tool requirements based on the feedback from the Week 1 interviews is described.

The aim of gathering feedback about the relative importance of the tool requirements during the Week 1 interviews was to help generate a set of what Ritzén and Lindahl (2001) described as 'contextual tool criteria'. This was done within this research by summarising the design team needs into five or six requirements that were subsequently used to evaluate the customised tools at the end of the Week 2 workshops.

A six-step process was used to develop the customised requirements, as is described here:

1. Review the quantitative data - The requirement importance scores from all interviewees within a given company were compiled into a table. The mean requirement importance score was calculated for each requirement and the requirements given a rank order. The actual data from Medipro is shown in Table 6.8.

Requirement	**Participant**			**Mean**	**Rank**
	A	B	C		
Time efficient	4	5	4	4.3	2
Easy to learn, use and understand	3	4	5	4.0	4
Use in early phases	3	5	4	4.0	4
Use of low quality data	4	3	3	3.3	6
Life cycle perspective	5	4	4	4.3	2
Marketing aspects	1	2	4	2.3	7
Use by a multi-functional team	2	2	2	2.0	8
Other	5	5	5	5.0	1

Table 6.8: The requirement importance score table from Medipro

Figure 6.10 presents a summary of the requirement importance scores recorded across all four cases. This type of comparison was not possible during the development of the customised tool requirements within the first three cases. However, it is interesting to note that the score are relatively consistent across the four cases. This result undermines to some extent the argument that eco-innovation tools must be customised to the specific needs of a company and its design team in order to be successful. Logically, if the design team needs, as expressed by the tool requirements, are similar, then a tool that works well in one company should work well in all the companies. However, the quantitative data does not reveal some of the important subtleties in the needs expressed by the design teams. This is explained further later in this section.

2. Review the qualitative data - At this stage in the research, the interview data had not been transcribed or coded as this was not feasible in the short time frame between the Week 1 and Week 2 activities. However, the comments relating to the requirements on the feedback form were reviewed and sections of the original audio were replayed where it was deemed necessary to clarify understanding of comments made by the interviewee.

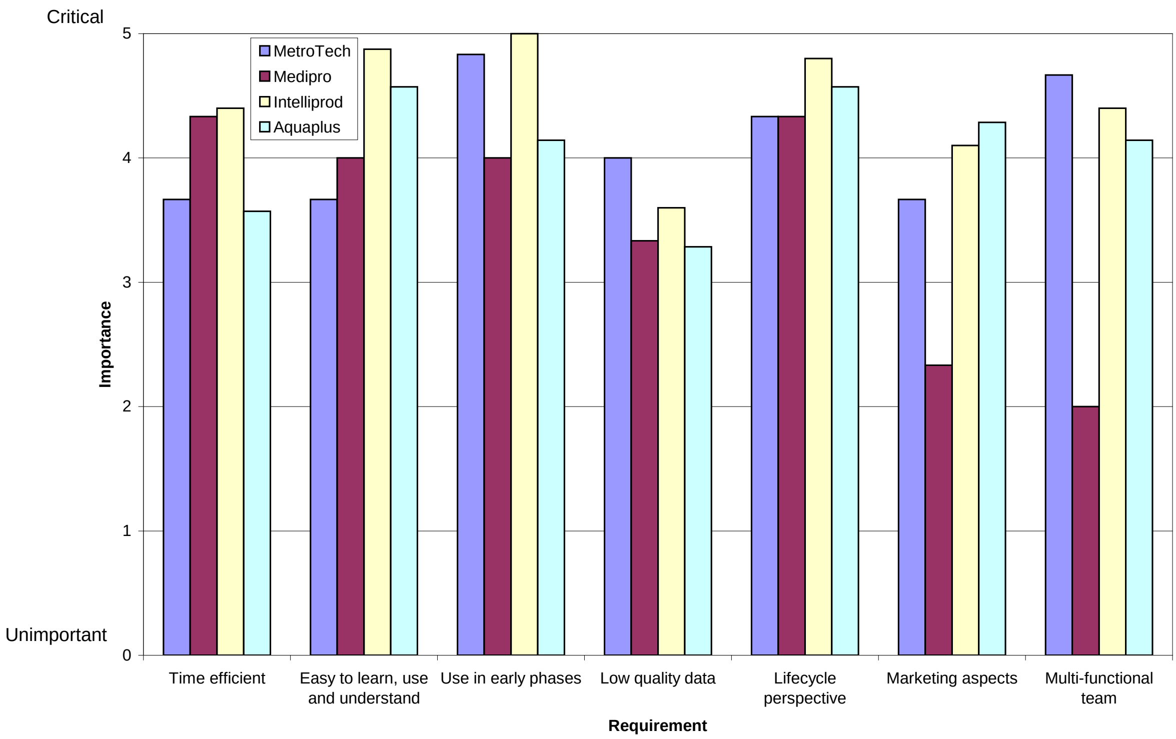

Figure 6.10: Comparison of the relative importance of the eco-innovation tool requirements across the four case-study companies

3. Eliminate the least important requirements - Having reviewed this quantitative and qualitative data, the least important requirements for each case were eliminated. In the case of Medipro, the three lowest ranked requirements were eliminated as they had received significantly lower scores than the rest of the requirements.

4. Review the requirements mentioned under the 'Other' category – As a variety of different requirements had been mentioned by interviewees within the 'other' category, these were reviewed to try and find some common theme. For example, within Medipro all three interviewees mentioned the need to assess the value of the tool in terms of the ideas that were generated. One participant was particularly keen to assess what ideas the tool helped the design team to generate that they would not have thought of otherwise. Hence a new requirement entitled ‘Generates new ideas’ was created as part of the contextual tool criteria for Medipro.

5. Develop operationalised definitions of the requirements - An ‘operationalised requirement’ is a requirement that is clearly understood by relevant stakeholders and the fulfilment of that requirement can be checked in an objective manner. This involved trying to relate the requirements to specific aspects of the company’s existing innovation practices and rephrasing the definitions to reflect the language of the company.

Examples of the operationalised tool requirement can be found within Table 6.9, which presents the customised set of requirements generated for each of the case-study companies. The first requirement within the Medipro column is entitled ‘Early phases’, which is similar to one of the titles found in the original set of generic requirements. However, for Medipro the definition of this requirement has been adapted to be more specific and relevant to the design team by adding the detail that ‘The tool can be applied during Advanced Concept Development activities’. ‘Advanced Concept Development’ was a term used within Medipro to refer to a specific stage of the innovation process within Medipro and hence by using this terminology there was an improved chance of gaining a common understanding between the participants (and the researcher) about the meaning of the requirement. Similarly, requirement three for Intelliprod has adapted the ‘Easy to learn and use’ requirement, making it more operational by giving the guidance “The tool is easy enough to learn and use that we would happily apply it in a one-off session with colleagues from other business functions or external partners who had no prior experience of it.”

6. Validation of the requirements - To validate the customised requirements they were presented to either the design team or the research coordinator for approval, prior to their use in the Week 2 workshops.

When completing this process with MetroTech, one interesting finding was that the criteria for time-efficiency was not considered to be very important. This was based on four comments from three different interviewees who stated that a significant amount of time could be spent in applying a tool if it was felt that using it would lead to significant insights, developments or new thinking. As one interviewee put it: *‘Being time efficient is less important, it is more a question of the effort-to-benefit ratio’*. This finding is surprising and significant because the academic literature argues that time efficiency is an important requirement for eco-design tools (Lindahl 2005; Luttrop 2006).

MetroTech	Medipro	Intelliprod	Aquaplus
1. Helps me to consider all the eco-options early *"This tool helps me to consider the whole life-cycle of the product and can be used before the Phase C review."*	**1. Early phases** *"The tool can be applied during Advanced Concept Development activities."*	**1. Early phases** *"The tool can be applied in activities prior to POD writing and the definition of a concept specification."*	**1. Early phases** *"The tool can be applied effectively during the early stages of a New Product Development project."*
2. Quality of outputs *"This tool helps to solve problems and generate novel ideas."*	**2. Generates new ideas** *"Helps us get to new ideas that we might not have thought of otherwise."*	**2. Value to the business** *"The tool adds value to the business by helping us to come up with innovative solutions and is useful for both eco-innovation and 'normal' projects."*	**2. Valuable ideas** *"The tool will benefit the company by helping us to generate, evaluate and progress valuable ideas."*
3. Easy to pick up when I need it *"I could come back to this tool in 6 months and use it again with 15 minutes revision."*	**3. Easy to learn and use** *"The tool is simple enough that I could introduce it to a colleague and begin using the tool effectively in less than one hour."*	**3. Easy to learn and use** *"The tool is easy enough to learn and use that we would happily apply it in a one-off session with colleagues from other business functions or external partners who had no prior experience of it."*	**3. Easy to learn, use and understand** *"The tool is easy enough to learn and use that we would happily apply it in a one-off session with colleagues from other business functions, customers or suppliers who had no prior experience of it."*
4. Helps me to think about the value created for the customer and Renishaw *"This tool helps me to see how we can market the product to the customer and what the project is worth to MetroTech."*	**4. Life cycle perspective** *"The tool helps us to consider the environmental impacts of the entire life cycle of the product and can help us choose which issues to focus on."*	**4. Finding the right focus** *"By making us think about all the environmental impacts of our product, the tool helps us to select issues where we can have a significant beneficial impact "*	**4. Green issues** *"The tool makes us think about all the different environmental impacts of the product and the different ways of being 'green'."*
5. Helps me to capture and record requirements *"This tool provides new ways of thinking about the customer's requirements and can help to structure*	**5. Time efficient** *"Using this tool would not create a risk of us missing project deadlines."*	**5. Time efficient** *"This tool could be applied from start to finish in a 2 hour session."*	**5. Time efficient** *"We can apply the tool effectively within a 1.5 hour session."*

and record these ideas."			
6. Integrates people and processes *"This tool facilitates working with others, sharing learning and has a clear place in the wider process."*		**6. Marketing aspects** *"The tool helps us to think about marketing aspects, including the benefits for the user and consumer education requirements."*	**6. Marketing aspects** *"The tool helps us to think about how the product will be marketed and the intended retail price."*

Table 6.9: The customised requirements used to evaluate the eco-innovation tools during the Week 2 activities

If this is not the case for eco-innovation tools then this indicates that it the requirements design teams have of eco-innovation tools are not always the same as requirements that they have of eco-design tools

The point was made earlier that the needs of the design teams appeared to be fairly similar when considering the quantitative data only. However, the analysis of the qualitative data revealed that there were subtle but important differences in the needs of the design team that the quantitative data did not capture. What this has shown is that there can be many different interpretations of what makes a design tool, 'time efficient', or 'easy to learn and use'. This point was previously made by Lindahl (2005) and strengthens the case for developing contextual tool criteria as it is through this process of discussing tool requirements with the design team that it was possible to arrive at more detailed requirements, formulated in a way that made them more understandable and relevant for the design team and the company.

In addition, having found some important differences in the needs expressed by the design teams, this strengthens the argument for adopting a tool customisation strategy because it suggests that a tool that works well in one company might not be successful in another company because of the differences in the needs of the design team. Tool customisation is a suitable solution to this problem.

In summary, this section has explained how, within each case-study company, an understanding of the needs of the design team was developed by: introducing the eco-innovation tools through a series of workshops; conducting individual interviews to gain feedback on the tools and the interviewee's general requirements of eco-innovation tools; and using this feedback to develop a set of customised tool requirements. It was concluded that during the process of developing customised tool requirements the qualitative data was particularly important as it was in these data that the subtle but important differences in the design team needs emerged, helping to create more specific and operational tool requirements. It was also concluded that the requirements design teams have of eco-innovation tools exhibit some differences from the requirements design teams have of eco-design tools. In the following section details of how the eco-innovation tools were customised, informed by the customised tool requirements and other insights, are presented.

6.5 Customising tools to company-specific requirements

This section explains how the eco-innovation tools were customised by first assessing what aspects of the tools needed to change, then making customisations to the tools. This process is illustrated through detailed descriptions of some of the tool customisations completed.

6.5.1 Tool customisations at MetroTech

This sub-section describes the tool customisations completed at MetroTech. The general strategy adopted for customising the eco-innovation tools began by deciding what aspect of the tool needed to be improved. This involved using both the quantitative and qualitative feedback from the Week 1 individual interviews and insights from the benchmarking activities. The quantitative data from the Week 1 interviews was used by comparing the performance of the tool against the tool requirements, taking into account the relative importance of the requirements and any new requirements that had been suggested by participants. Figure 6.11 shows this comparison for the MetroTech case. The main 'performance gaps' (i.e. where the actual performance of the tool was scored poorly compared to the importance of the requirement) were for the 'use in early phases' and the 'life cycle perspective' requirements.

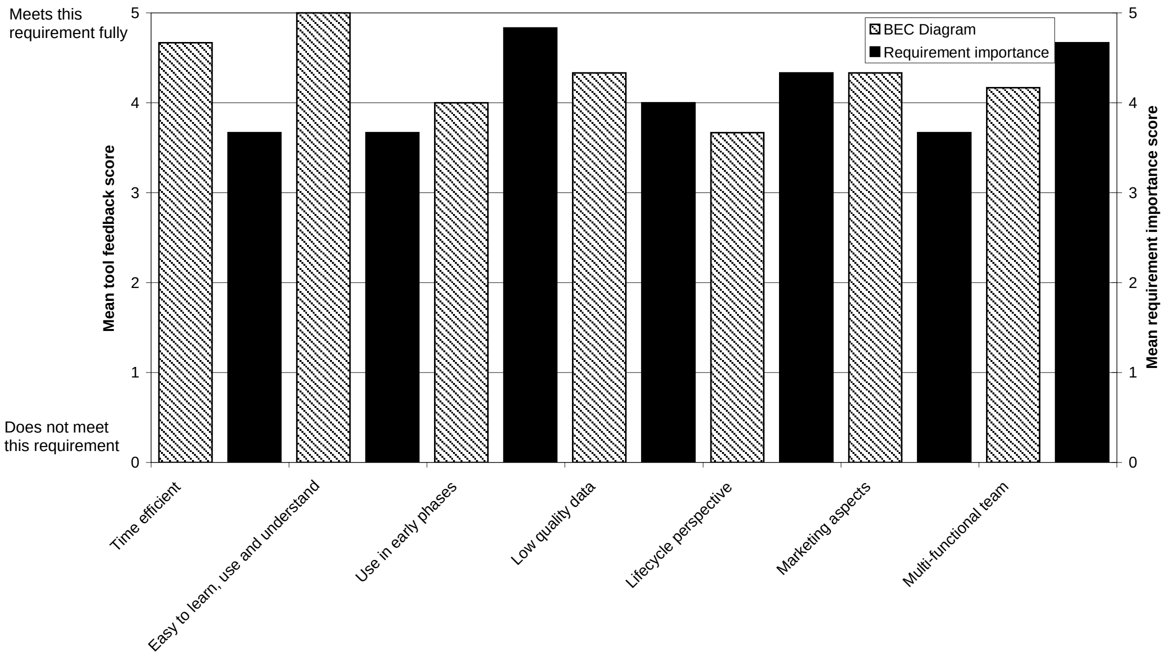

Figure 6.11: Performance of the generic tools at MetroTech compared to the importance of the requirements

The need to provide more support for understanding the product life cycle and environmental aspects was reinforced by the benchmarking activities in which MetroTech did not score well on the environmental benchmarks.

The qualitative data from the Week 1 interviews was briefly reviewed and the following key points were noted specifically about the BEC Diagram tool:

- the tool was useful because it visually summarised the main requirements of the product and showed the stakeholder benefits;
- the design team appreciated the fact that the tool was simple to use;
- there was a need to ensure that the outputs of the tool would lead to 'commercially viable' product ideas;
- whilst the tool highlighted aspects of the design that could be improved, it was felt that including some kind of stimulus or prompts might be useful to when developing ideas of how to make improvements.

The 9 Windows had not been tested during the Week 1 activities due to time constraints. Therefore, the feedback about the 9 Windows tool from the one-day workshop was reviewed instead. The main point noted at that time was that it was difficult to know what type of environmental problem to focus on at the start of the process i.e. choosing the title of the centre window.

With these general and specific tool issues in mind, the researcher then made a number of customisations to both the BEC Diagram and the 9 Windows tools to try and rectify these problems, as summarised in Table 6.10.

Tool	**Strengths**	**Weaknesses**	**Customisation**
BEC Diagram	• Simple and visual • Quick to use • Can be used by a multi-functional team • Can cope with low-quality data	• Highlights areas for improvement but more help in generating ideas needed • Does not encourage thinking about the whole product life cycle • Need to check the commercial viability of the tool outputs	• Use strategies from LiDS wheel (Brezet, 1996) as prompts for idea generation • Use business value of ideas matrix
9 Windows	• Not trialled in week 1	• Difficult to select the environmental problem to tackle	• Use the MET matrix (Brezet and van Hemel, 1997a) to define the environmental problem

Table 6.10: Summary of the main tool strengths and weaknesses and the tool customisations completed at Metrotech

For the BEC Diagram tool, to help the generation of ideas a prompts sheet including some of the eco-design strategies from the LiDS wheel (Brezet, 1996) was created. These would be distributed to the participants at the start of the activities. To address the need to check the commercial viability of the outcomes of the tool, the 'Business Value Evaluation Matrix' was created. The 'Business Value Evaluation Matrix' was based on the Boston Consulting Group's portfolio management matrix (Henderson, 1979) and involved placing the concepts that had been generated during the session in a 2x2 matrix with axes of 'Market value' (high/low) and 'Market volume' (high/low). The aim was to prioritise the ideas according to their potential value to the business by selecting concepts that were in line with the company strategy (generally high value, low volume for MetroTech).

For the 9 Windows tool, to make it easier to define the central environmental problem and also to help promote a better understanding of the product life cycle, the MET matrix tool (Brezet and van Hemel, 1997a) was incorporated into the tool application process. The MET matrix is a simple, qualitative tool for environmental impact assessment. The customised 9 Windows tool would use the MET matrix to highlight some of the more significant environmental impacts of the product, from which one could be chosen to form the environmental problem within the centre window of the tool e.g. 'energy use during the manufacturing phase', or 'toxic emissions during the end-of-life phase'.

The effectiveness of these tool customisations is reviewed in Section 6.6.2 whilst in the following section the tool customisations at Medipro are described.

6.5.2 Tool customisations at Medipro

Figure 6.12 compares the tool feedback scores for the 9 Windows tool from the Week 1 activities at Medipro with the importance of the tool requirements. It can be seen that the main performance gap was related to the requirement 'Easy to learn, use and understand'. Analysis of the qualitative data from the Week 1 interviews had highlighted a need for the tool to prove that it could help generate ideas that would not normally have been thought of. This led to the creation of the customised tool requirement 'Generates new ideas', as shown in Table 6.10.

The qualitative data from the Week 1 interviews was briefly reviewed and the following key points were noted about the 9 Windows tool:

- The tool was useful in promoting consideration of the product life cycle
- It was felt that the tool could be applied effectively during the early phases of the innovation process.
- The main difficulty was in defining the windows and understanding what types of issue should be considered within a given window.

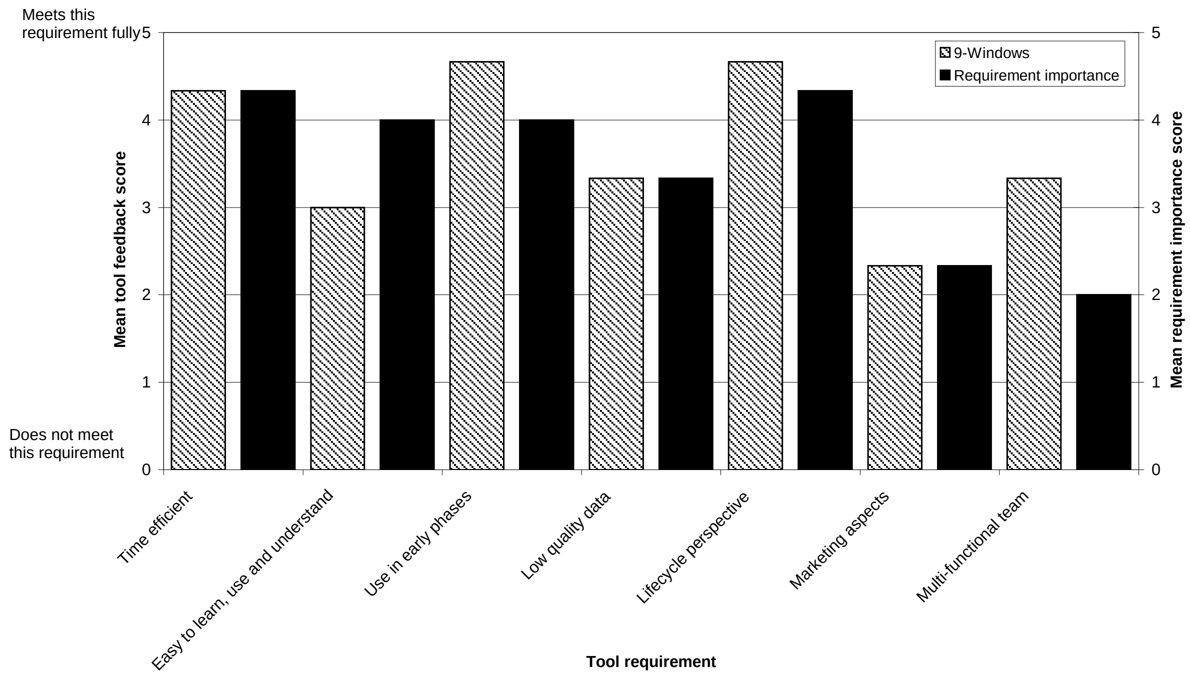

Figure 6.12: Performance of the generic tools at Medipro compared to the importance of the requirements

- It was suggested by several participants that without defining a follow-up process any good ideas that came out of a session would probably not be progressed further.

With these general and specific tool issues in mind, the researcher then made a number of customisations to the 9 Windows tool to try and rectify these problems, as summarised in Table 6.11.

Strengths	Weaknesses	Customisation
• Promotes consideration of entire product life cycle • Can be used in early phases of innovation	• Difficult to define windows • No follow-up process defined	• Reduce to six windows • Pre-specify window titles • Use 6 Windows die • Time limit of four mins. per window • Evaluate ideas and define follow-up actions as part of activity

Table 6.11: Summary of the main tool strengths and weaknesses and the tool customisations for the 9 Windows tool at Medipro

The main customisations made to the 9 Windows tool where inspired by a comment from a member of the design team during one of the Week 1 feedback interviews. He had suggested placing a description of the environmental problem to be tackled on one face of a ‘paper box’, with alternative views of the problem on the remaining faces. This idea had a number of advantages over the original format of the tool. First, the paper box would act as a physical analogy to the principle of taking different viewpoints on a problem – the design team could now physically look at the different 'faces' or 'windows' of the problem. Secondly, by reducing the number of windows from nine to six, applying the tool was likely to be both simpler and quicker.

In the final version of the tool, the environmental problem was not written on the box but was written in the centre of a sheet of flipchart paper. The rest of the paper was divided into six portions, each of which corresponded to one of the faces of the box, as shown in Figure 6.13. Another customisation was to pre-specify the titles of each of the windows. The intention of this was to make the tool easier to use by removing the task of deciding on the window titles.

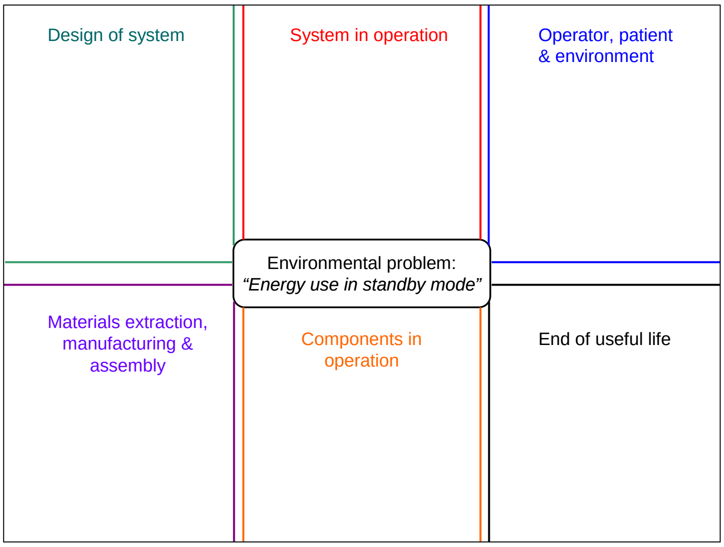

Figure 6.13: The blank worksheet for the customised 9 Windows tool at Medipro

The window titles were:

- Materials extraction, manufacturing & assembly
- Design of system
- System in operation
- Components in operation
- User & operating environment
- End of useful life

The window titles emphasised the environmental life cycle of the product, from materials extraction through to the end of the product's useful life. This reflected the fact that Medipro has significant experience of eco-design and hence the design team were comfortable using this type of environmental life cycle terminology. Furthermore, Medipro was proactive in managing the environmental impacts of their supply chain and hence they were keen to consider issues such as materials extraction and the manufacture of bought-in components.

The final customisations were related to how the tool session was run. First, a time limit of four minutes per window was set for the problem analysis phase. This was set to avoid the situation in which the design team become ‘stuck’ or fixated on one particular window. Secondly, formal idea evaluation and follow-up activity definition phases were written into the tool process description to help ensure that any good ideas coming out of the tool would be taken forward for further development.

The effectiveness of these tool customisations is reviewed in Section 6.6.2 whilst in the following section the tool customisations at Intelliprod are described.

6.5.3 Tool customisations at Intelliprod

Figure 6.14 compares the tool feedback scores for the 9 Windows and SFR tools from the Week 1 activities at Intelliprod with the importance of the tool requirements. It can be seen that the main performance gaps were related to the requirements:

- ‘easy to learn, use and understand’, and ‘time efficient’ for the 9 Windows tool;
- ‘easy to learn, use and understand’, and ‘life cycle perspective’ for the SFR tool.

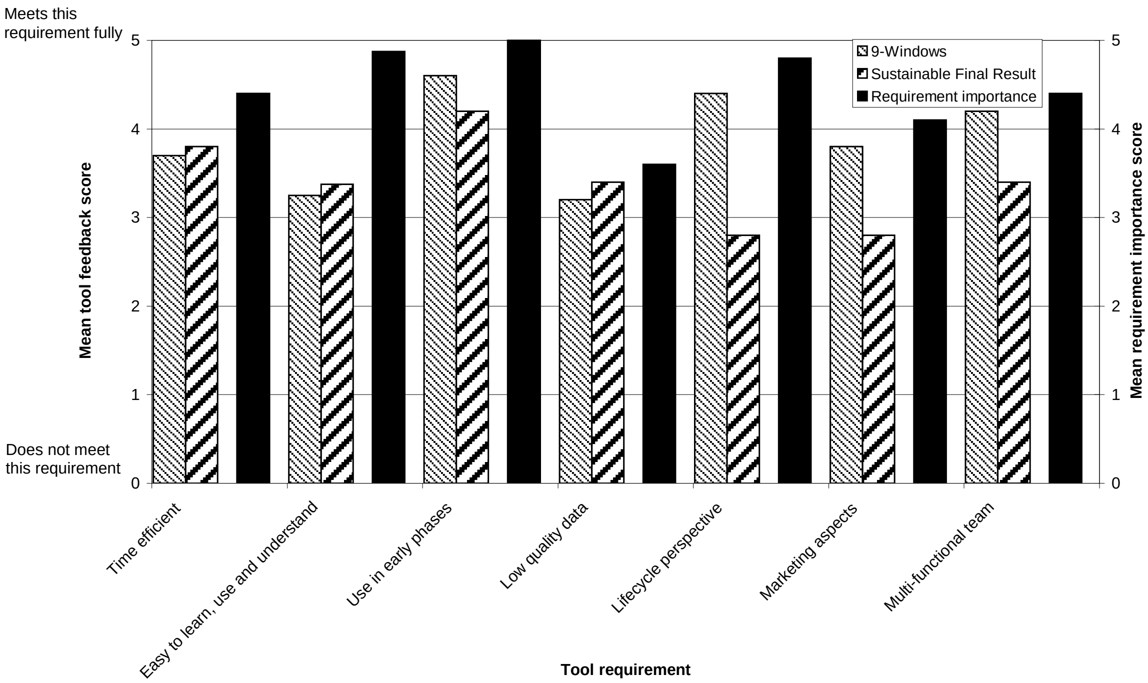

Figure 6.14: Performance of the generic tools at Intelliprod compared to the importance of the requirements

The qualitative data from the Week 1 interviews was briefly reviewed and the following key points were noted about the 9 Windows tool:

- It was considered to be beneficial to idea generation because of the structure it imposed which led to new approaches to the problem being raised.
- It was also felt to be useful for encouraging consideration of the entire product life cycle.

- The main problem with applying the tool was that the design team were not familiar with the terminology of ‘systems levels’.
- It was also noted that there was a risk that a team applying this tool could become overly focused on simply filling up the windows, rather than really thinking about different perspectives on the problem.

The following key points were noted about the SFR tool:

- The tool encouraged more radical and long-term thinking and therefore could be of use in defining the future product or company strategy.
- There was concern that it was very easy to ‘set off down the wrong path’ (i.e. follow a line of logic that lead to ‘utopian’ ideas or ideas that were not relevant to the company) and that this could lead to disappointment and frustration.
- The design team wanted the tool to be more visual.

Regarding the needs of the company, it was noted that Intelliprod did not have much experience of applying design or creativity tools and that they had shown limited performance in terms of environmental actions and would therefore possibly benefit from tools which were simple but increased their environmental knowledge. With these general and specific tool issues in mind, the researcher then made a number of customisations to the 9 Windows and SFR tools to try and rectify these problems, as summarised in Table 6.12.

Considering first the customisations made to the 9 Windows tool, one design team member had commented during an interview that the she had found this tool to be too complicated, particularly the terminology used (‘subsystem’, ‘supersystem’ etc.). She therefore suggested that the tool be simplified to incorporate just three windows and that these windows should be titled ‘before use’, ‘during use’ and ‘after use’. These suggestions were implemented within the final version of the tool with some minor modifications, as shown in Figure 6.15.

First, the nine windows were reduced to five rather than three which was considered to be a compromise between simplifying the tool and still encouraging some consideration of different systems levels.

Secondly, the titles of the windows were pre-specified as suggested but the titles were more specific in an attempt to reflect the interests, requirements and language of the design team and the company. The titles were:

- Contemplation – 5 minutes before use;
- Product in use;
- Product features and components in use;

Tool	Strengths	Weaknesses	Customisation
9 Windows	• Provides structure and focus to idea generation • Promotes consideration of entire product life cycle • Forces consideration of aspects that might not normally be covered	• Difficult to understand 'systems level' axis • Easy to become overly focused on filling-in all nine windows	• Reduce to five windows • Time limit of 4 mins per window • Focus on user behaviour • Pre-specify window titles • Evaluate ideas and define follow-up actions as part of activity • Use as an 'eco' or 'non-eco' tool
SFR	• Promotes more radical thinking • May be of use in defining long-term strategy	• Easy to set-off down the 'wrong' path or generate 'utopian' solutions • May lead to disappointing or challenging conclusions i.e. 'self ironing clothes' • Less visual	• Use of the 'Functions-values matrix' to help focus on rooms of the house • Generation of intermediate ideas to help create 'road map' • Use as an 'eco' or 'non-eco' tool

Table 6.12: Summary of the main tool strengths and weaknesses and the tool customisations completed at Intelliprod

- Household environment and user behaviour;
- Completion, conclusion – 5 minutes after use.

The 'contemplation' title was chosen because it had been mentioned that the marketing team had previously held a brainstorming session to think about what a user would be doing immediately before commencing use of the product. Also, the Innovation Director at the company noted that they had recently received the results of a large piece of market research which highlighted some of the main user profiles for Intelliprod-type products. They were therefore very keen to understand how thinking about the *experiences* of these different types of user when interacting with the product could become a stimulus for innovation. The rest of the window titles therefore reflect this strong interest of Intelliprod in user behaviour and the activities surrounding the use of the product.

The final customisation to the tool was the inclusion of small icons to represent each of the different windows. It has previously been suggested that the inclusion of icons within design tools can help users to recall eco-design strategies (Luttropp and Lagerstedt, 2006). Unfortunately the icons were relatively basic in style and appearance as there was insufficient time and budget to employ a graphic designer.

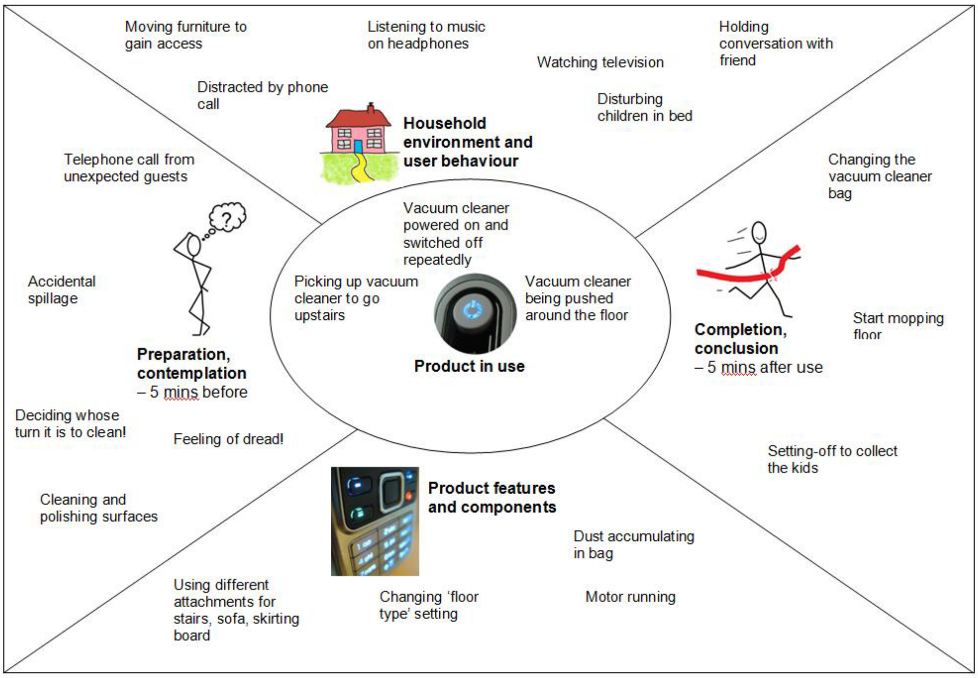

Figure 6.15: The final version of the 9 Windows tool customised for Intelliprod completed for the example of a vacuum cleaner

Considering next the SFR tool, to overcome the performance gap associated with the 'life cycle perspective' requirement, it was proposed that the team run through a MET matrix (Brezet and van Hemel, 1997a) at the start of the exercise to remind themselves of the typical environmental impacts of the product. This proposed customisation was rejected by the Innovation Director during a review prior to the start of the Week 2 activities. Instead, the Innovation Director suggested that he wanted the design teams to be thinking about the environment in which the product was being used and the types of functions that were performed in that environment and the values embodied in the environment. It was therefore decided to incorporate this into an exercise in which the participants would create a 2x2 matrix of 'functions' and 'values' along one axis and 'today' and year 2030' along the other axis. The aim of completing this 'Functions-values' matrix was to think about how the functions performed in an environment like the domestic kitchen and the values associated with that environment might change over the next 20+ years. Whilst this exercise did not encourage the participants to think about the life cycle environmental impacts of the product as the MET matrix exercise would have done, it was decided to implement the 'Functions-values' matrix because it was more in line with the product and innovation strategy of the company.

To tackle the other performance gap relating to the ease of learning and use of the tool it was proposed that after coming up with the Sustainable Final Result statement, the design team would summarise it on a sticky note and place it on a cone diagram, as shown in Figure 6.16. The team would then begin generating ideas for intermediary products – products that did not exist currently but were not as radical as the solution

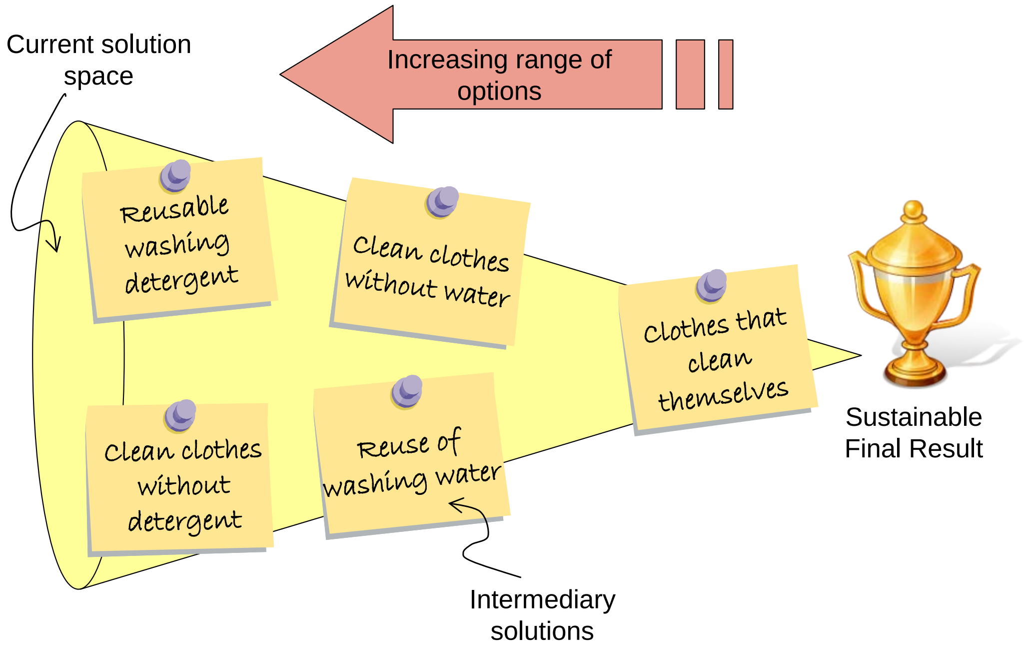

Figure 6.16: Example of the intended use of the innovation cone for the customised SFR tool

described by the Sustainable Final Result. These intermediary ideas were also written down on sticky notes and placed on the cone diagram with the more radical ideas towards the pointed end of the cone and the less radical ideas placed towards the base of the cone. It was hoped that physically laying out the ideas within this diagram, rather than simply listing ideas on a sheet of paper, would make the tool easier to use by helping the team to visually identify the different lines of thinking and where there was a significant gap between a radical idea and a very incremental idea which might need to be filled with an intermediate idea.

6.5.4 Tool customisations at Aquaplus

Figure 6.17 compares the tool feedback scores for the 9 Windows and SFR tools from the Week 1 activities at Intelliprod with the importance of the tool requirements. It can be seen that the main performance gaps were related to the requirements:

- ‘life cycle perspective’ for the BEC Diagram tool; and
- ‘life cycle perspective’ and ‘marketing perspectives’ for the SFR tool.

The qualitative data from the Week 1 interviews was briefly reviewed and the following key points were noted about the BEC Diagram tool:

- The tool was liked for its simple, visual and intuitive ‘interface’ which it was felt could easily be used by a variety of different company functions.
- Because Aquaplus sell their products to large retailers who then sell them on to end users, there was some confusion about who ‘the customer’ was.

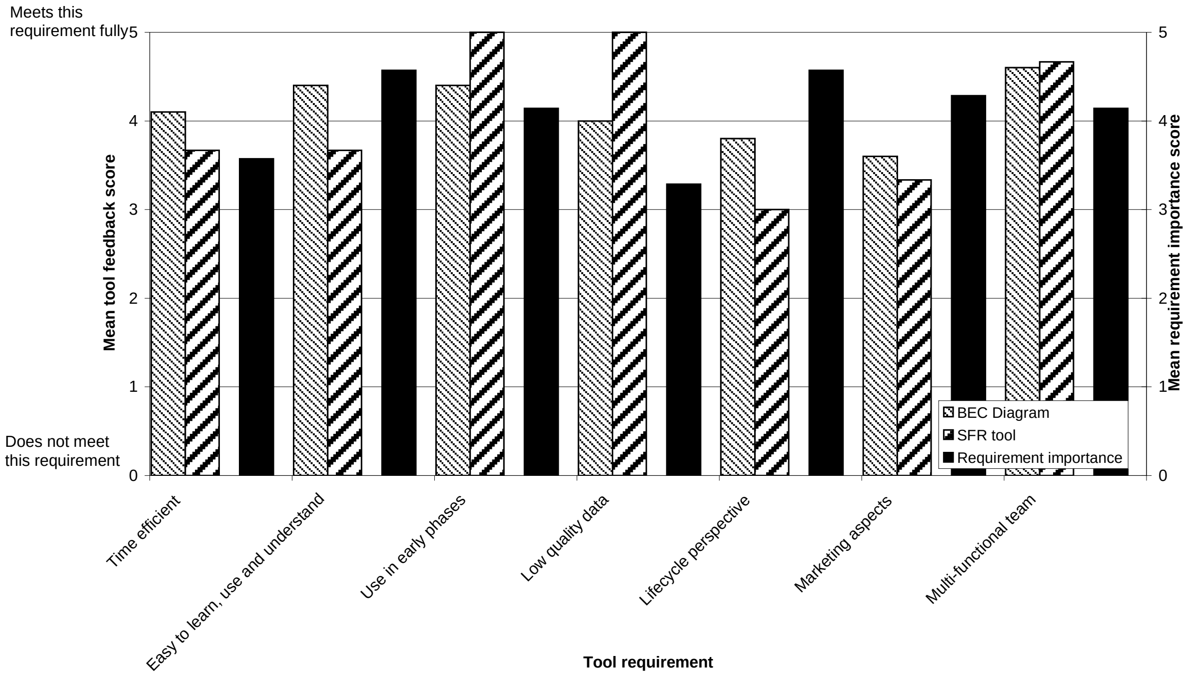

Figure 6.17: Performance of the generic tools at Aquaplus compared to the importance of the requirements

The following points were noted about the SFR tool:

- Whilst the overall principle of the tool was considered easy to understand, the wording of the 'structured thinking questions' was confusing for some.
- When working through the structured thinking questions a large number of different lines of enquiry were being discussed. This meant that it was difficult for the team to follow one particular idea through the whole process.
- The main benefit of the SFR tool was its ability to encourage 'blue sky' thinking and generate a broad range of ideas very quickly.

Regarding the needs of the design team, the several interviewees suggested that they would like to have some method for evaluating ideas incorporated within the tool. In particular, they were keen to understand the possible cost implications of the ideas being generated. With these general and specific tool issues in mind, the researcher then made a number of customisations to the BEC Diagram and SFR tools to try and rectify these problems, as summarised in Table 6.13.

The main customisation made to the BEC Diagram was to split the activity across two diagrams. Both were essentially the same as a normal BEC Diagram except that the first covered only the issues up to the 'point of sale to the end user'. Hence for this diagram the 'customer' was the retailer and the 'environment' only considered issues associated with raw materials extraction, manufacture and distribution. The second diagram covered the remainder of the product life cycle and so the 'customer' was the end user and the

Tool	Strengths	Weaknesses	Customisation
BEC Diagram	• No data or preparation required. • Simple, visual ‘interface’.	• Does not consider product life cycle • Not clear who ‘the customer’ is.	• Split into two diagrams – one covering up to ‘point of purchase by end-user’, second ‘after point of purchase’. • Idea evaluation form completed
SFR	• Quickly generates new ideas. • Encourages ‘blue-sky’ thinking.	• Wording of structured thinking questions confusing. • Easy to stray off topic when answering the structured thinking questions. • Does not consider product life cycle.	• Wording of structured thinking questions simplified. • Worksheet modified so that one idea is considered at a time. • Idea evaluation form completed.

Table 6.13: Summary of the main tool strengths and weaknesses and the tool customisations completed at Aquaplus

‘environment’ considered issues associated with product use, maintenance and disposal. The aim of this customisation was to promote more consideration of the product life cycle and to eliminate the confusion over which ‘customer’ was being considered.

The other customisation was to evaluate the ideas generated during the session using a structured evaluation form. This involved writing a brief summary of the idea and then describing the benefit to the business, the customer and the environment. This benefit was compared to the benefit offered by a reference product and scored from -2, ‘significantly worse than the reference product’, to +2, ‘significantly better than the reference product’.

The two main customisations made to the SFR tool were to simplify the wording of the structured thinking questions and changing the tool worksheet so that only one idea or line of enquiry was considered at a time. The latter involved writing all the answers to the first structured thinking question on sticky notes. One obstacle was then chosen and the rest of the process completed for this obstacle. This process was repeated for the rest of the obstacles identified initially but by working through this process with one obstacle at a time, the risk of the participants losing track within the process was reduced.

Although not tested during the Week 1 activities, it was decided to apply the 9 Windows tool within the Week 2 workshops. This was because the participants from the Week 1 workshops had felt that the activities were producing business strategy ideas or ‘blue sky’ product concepts but not enough product ideas that could be implemented within the short-term. The customisations made to the 9 Windows tool were based on the fact that ease of learning and use was the second most important tool requirement at Aquaplus, something that the 9 Windows tool had scored poorly on at the one-day workshop. Given that reducing the number of windows and pre-specifying the window titles had proven to be successful strategies for improving the ease of use of this tool within Medipro and Intelliprod, it was decided to utilise these tool customisation strategies again. Hence, the tool was reduced to six windows, and presented in the same format as at Medipro (see Figure 6.12) but with the following window titles:

- ‘Manufacturing, assembly and distribution’,
- ‘Preparation – five minutes before shower use’,
- ‘Shower in use’,
- ‘User behaviour and household environment’,
- ‘Shower components and features in use’,
- ‘Drying off – five minutes after use.’

This section has discussed the participant feedback from the week one workshops and demonstrated how this was used to inform the tool customisations within each of the case study companies. This information is summarised in Table 6.14.

	Tool	Strengths	Weaknesses	Customisation
MetroTech	BEC Diagram	• Simple and visual • Quick to use • Can be used by a multi-functional team • Can cope with low-quality data	• Highlights areas for improvement but offers no help in generating ideas • Does not help you think about the product life cycle • Does not stress commercial aspects enough	• Use strategies from LiDS wheel (Brezet, 1996) as prompts for idea generation • Use business value of ideas matrix
	9 Windows	Not trialled in week 1	Not trialled in week 1	• Use the MET Matrix to establish the environmental focal issue
Medipro	9 Windows	• Promotes consideration of entire product life cycle • Quick to use • Can be used in early phases of innovation	• Difficult to define windows • No follow-up process defined	• Reduce to six windows • Time limit of 4 mins per window • Pre-specify window titles • Use 6 Windows die • Evaluate ideas and define follow-up actions as part of activity
Intelliprod	9 Windows	• Provides structure and focus to brainstorming • Promotes consideration of entire product life cycle • Forces consideration of aspects that might not normally be covered	• Difficult to understand 'systems level' axis • Easy to become overly focused on filling-in all nine windows	• Reduce to five windows • Time limit of 4 mins per window • Focus on user behaviour • Pre-specify window titles • Evaluate ideas and define follow-up actions as part of activity • Use as an 'eco' or 'non-eco' tool
	SFR	• Promotes more radical thinking	• Easy to set-off down the 'wrong' path or generate 'utopian'	• Use of the 'Functions-values matrix' to help focus on rooms of

		• May be of use in defining long-term strategy	solutions • May lead to disappointing or challenging conclusions i.e. 'self ironing clothes' • Less visual	the house • Generation of intermediate ideas to help create 'road map' • Use as an 'eco' or 'non-eco' tool
Aquaplus	BEC Diagram	• Quick and easy to learn • Encourages participation from different business functions • Simple and visual	• Does not explicitly encourage consideration of the product life cycle • Tended to highlight known conflicts and opportunities • Does not help to evaluate ideas	• Have two BEC Diagrams, one for each half of the product life cycle • Use of TRIZ 'Inventive principles' to resolve conflicts • Use 'Eco-innovation idea evaluation form'
	SFR	• Promotes more radical thinking • Could be applied to other issues – not just 'eco'	• Attempting to simultaneously follow multiple lines of thought confusing • Need more help to guide through structured thinking questions • Does not help to evaluate ideas	• Use the MET Matrix to establish the environmental focal issue • Use separate worksheets to work through one line of thinking at a time • More relevant structured thinking questions examples provided • Use 'Eco-innovation idea evaluation form'
	9 Windows	Not trialled in week 1	Not trialled in week 1	• Reduce to six windows • Time limit of 4 mins per window • Pre-specify window titles • Use 6 Windows die • Use of the 'Eco-innovation idea evaluation form'

Table 6.14: Summary of the tool feedback from the week one workshops and the subsequent tool customisations for each case study

6.6 Review of the effectiveness of the tool customisations

In this section, the effectiveness of the tool customisations are reviewed by considering the results of the Week 2 workshops, the feedback scores and comments from the workshops, and the comments from the design team provided during the in-depth feedback interviews. This analysis is reported on a case-by-case basis over the four following sub-sections before the cross-case comparative analysis in sub-section

6.6.1 Methodology for the Week 2 activities

The Week 2 workshops differed from the Week 1 workshops in the following ways:

- The tasks tackled within the workshops were based on real and specific projects5 that the company wanted to look at, which were provided by the research coordinator. Unfortunately the exact tasks cannot be described for confidentiality reasons.
- At the end of each session the design team completed a tool evaluation form based on the Week 2 tool requirements. For each of the requirements, the team were asked to provide a group score on a five-point scale ranging from one - 'does not meet this requirement' - through to five - 'meets this requirement entirely'. These group feedback sessions were transcribed and coded.

Table 6.15 provides a summary of the workshops completed with each of the tools within each of the case-study companies.

Company	9 Windows	Sustainable Final Result	BEC Diagram
MetroTech	1 Workshop, theoretical task	-	1 Workshop, real and specific task
Medipro	2 Workshop, real and specific tasks	-	-
Intelliprod	2 Workshop, real and specific tasks	1 Workshop, real and specific task	-
Aquaplus	1 Workshop, real and specific task	1 Workshop, real and specific task	1 Workshop, real and specific task

Table 6.15: Summary of the Week 2 workshops completed

[5] The task for the 9 Windows workshop at MetroTech was theoretical because this tool had not been applied by the design team and the research coordinator suggested that it would be easier for them to learn about the tool by applying it to a simple theoretical task.

In order to gain further feedback and insight into the performance of the customised tools, individual tool feedback interviews were conducted with a selected range of the design team members that had participated in the Week 2 workshops. Where possible, staff that had participated in Week 1 and Week 2 workshops with the same tool were selected to aid the comparison between the original and the customised tools. In each case, the research coordinator was included as part of this sample. The four main questions used in these interviews were:

1. Do you think the eco-innovation tools were suitably adapted to your particular needs?
2. Are there any aspects of the tool that you would like to change? (Any suggestions as to how to achieve this?)
3. Can you see yourself using the eco-innovation tool(s) in your work in the future?
4. What would make you more likely to use eco-innovation tools in your work?

As well as these tool feedback interviews, a small number of interviews were conducted with staff members that had not participated in the any of the workshop sessions but who it was considered may be able to provide useful opinions or insights on either:

- The introduction of design tools within the company – in particular questions were asked about previous attempts to introduce new design or innovation tools, the result of those activities and what were considered to be the success/failure factors.
- The organisational drivers and barriers for eco-innovation - interviewees were asked about the main drivers and barriers for eco-innovation and what might be done to reduce the barriers and strengthen the drivers.

The background and job role of the interviewees selected for these particular interviews varied widely but included an Estates Manager, a Sales Manager, a Purchasing Manager and an Engineer. The reader can refer to Table 3.7 in Section 3.6.1 for a summary of the number of tool feedback, tool introduction issues and drivers and barriers interviews completed during Week 2 within each of the case-study companies.

6.6.2 Effectiveness of tool customisations at MetroTech

Two tools were tested during the second week of activities at MetroTech, the BEC Diagram and the 9 Windows tools. Considering first of all the BEC Diagram tool, the main customisations were: integrating the use of the LiDS Wheel eco-design strategies in the form of a prompts sheet (shown in the Appendix); and the use of the ‘Business Value Evaluation Matrix’. Having introduced both of these customisations to the group, the Business Value Evaluation Matrix was dismissed by the design team as being unnecessary as the company already had a project screening system in place. This part of the activity was therefore not completed during the session.

The session proceeded normally, with all participants making useful contributions. When proposing a new idea of how to move one of the existing issues in to the ‘tri-synergies’ segment of the diagram, one of the participants specifically cited the prompts sheet as being the inspiration for the idea. Also, when there was a lull in the idea generation, one of the participants began reading some of the prompts out loud in an attempt to stimulate some more ideas within the group. This demonstrated that the participants were using the prompts sheet and that it had helped in generating at least one new idea. By the end of the one and a half hour session, the group had successfully completed the full activity and had managed to generate five product innovations that fell into the tri-synergies segment.

The tool feedback was positive, with the team agreeing that all the requirements had been met other than the ‘Helps me to capture and record requirements’ requirement which was given a neutral score. However, under the ‘Helps me to consider the value created for the customer and MetroTech’ requirement, the following comment was added: ‘Proof needed to show value of the tool/decisions’. Reviewing the audio transcript, it was found that this referred to a concern amongst the group that it would be difficult to demonstrate the business benefit from making improvements to the environmental performance of the product. It was suggested that having some indicator of the environmental impact of the product such that new products could be compared to old would be useful. This comment demonstrates that the design team were not familiar with Life Cycle Assessment tools that already provide this type of function.

Another interesting issue raised during the tool feedback was that some of the participants felt that they were not the correct audience for the tool as they almost always work on derivative projects (slight changes to existing products) rather than innovation projects. There was some discussion amongst the group as to how much freedom they had to suggest new ideas within their projects, particularly the project that had been used during the session. These comments suggest that the choice of project to test the tool on was not ideal. Instead a project should have been chosen which was in the earliest stages of the NPD process and which had an explicit brief to deliver innovation.

Considering now the 9 Windows tool, the customisations for this tool were based on the feedback comments from the one-day workshop. This was because the 9 Windows tool not been trialled during the first week of the tool introduction study. The only customisation to the tool was the requirement to complete a MET matrix for the product prior to commencing the normal activity. This was intended to help the design team to prioritise and select the environmental focal issue for the activity. The MET matrix was therefore introduced to the session participants and duly completed.

After some discussion, the participants were able to select an environmental focal issue based on the completed MET matrix. The session then proceeded as normal although, as it was the first application of the tool for the participants it had been decided to work on a theoretical problem ('energy use in mobile phones') rather than one of the company's own products. The group were able to populate the 9 Windows worksheet with relevant issues before selecting a few of those issues to generate solutions for. Partly due to the shortness of the session (one and a half hours), the team only had time to generate a few ideas. However, they were satisfied that they had seen the entire process of the tool and could complete an evaluation.

The feedback for the 9 Windows tool was more variable than for the BEC Diagram. The group agreed that the tool: helped to integrate people and process; helped to capture and record requirements; and that the outputs of the tool were novel and may not have been considered otherwise. However, they gave neutral responses to the requirements 'Easy to pick up when I need it' and 'Helps me to consider the eco-options early' and disagreed that the tool fulfilled the requirement of 'Helps me to consider the value created for the customer and MetroTech'. From the comments on the feedback form and the feedback transcript, it would seem that the main reasons for these unfulfilled requirements were:

- That it was difficult to gain consensus on what types of issues should be placed in each of the windows and so more practice and experience of using it would be required
- The design team would not be keen to complete a MET matrix every time they wanted to use the tool. However, they recognised that without the MET matrix part of the activity, the tool itself did not encourage thinking about the life cycle.
- The tool was more focused on solving specific problems than considering the commercial aspects of product development or marketing.

After both workshop sessions had been completed, in-depth feedback interviews were conducted with three of the project team members, including the Project Manager, as well as the Group Engineering Manager. From these interviews the following key points were highlighted regarding the effectiveness of the tools and the tool customisations:

- The eco-design strategies prompts sheet used as part of the BEC Diagram activity was considered a useful aid due to the level of detail provided in the prompts.
- All four design team members interviewed could envisage themselves using the BEC Diagram in their work again in the future in some form. For instance, one Project Manager felt that they would use the principle of considering business, environment and customer requirements but that they would further simplify the tool by converting it into three checklists - one for each stakeholder. These checklists could then be added

to throughout the duration of the project and used as a template for subsequent, similar projects.

- It was felt that the 9 Windows tool could be used for general problem solving, not just ‘eco’ purposes whereas the BEC Diagram would only ever be used for ‘eco’ projects.
- Because of its more limited scope for application, participants felt that they would need permission to use the BEC Diagram tool within a project. This permission would either come from the requirements specification (e.g. a set of strong environmental requirements), or from a direct request by a member of senior management.
- It was suggested that having a spreadsheet software version of the tools would help by allowing the results to be easily recorded, stored and shared.

Based on the feedback results and comments along with the comments from the in-depth interviews, it is concluded that the BEC Diagram tool customisations were successful and the 9 Windows tool customisations were not successful. However, it is also concluded that the 9 Windows tool is more likely to be used by MetroTech in the future. This apparently contradictory conclusion is justified by the argument that, although the BEC Diagram tool was suitable customised to the requirements of the design team, there was not sufficient interest in eco-innovation amongst the design team for them to use the tool in the future. This conclusion is made despite the fact that all the participants claimed that they would use the tool in the future. It is suggested that some of these responses were biased due to participants not wanting to disappoint the researcher by being overly critical of the tools. In contrast, the 9 Windows tool was found to be difficult to use by the design team but was more likely to be used because it performed a more generally applicable problem solving function that could still be useful outside of eco-innovation projects.

6.6.3 Effectiveness of tool customisations at Medipro

From the Week 1 activities it was found that the main performance gaps of the 9 Windows tool at Medipro were the difficulty in using the tool due to problems in defining what type of issue should appear in each of the windows and the lack of a follow-up process to ensure that the outputs of the tool were evaluated and implemented where appropriate. The customisations employed to try to overcome these issues were: reducing the number of windows to six with pre-specified titles, using a die with the titles of the windows on the sides of the die; limiting the time spent on each window to four minutes; and including additional steps in the tool application process to encourage participants to evaluate ideas and define follow-up actions. The tool was renamed the ‘Out of the Box’ tool, alluding to the idea that by moving out of the box of the problem you are able to see six different sides of the problem.

Two separate sessions were held using the Out of the Box tool. The first was aimed at eliminating a hazardous substance from the product, the second was aimed at reducing the energy consumption of a particular sub-system of the product. In both cases the tool customisations were introduced and a briefing on the aim of the session given. In the session aimed at reducing energy consumption, one of the participants suggested that it would be a good idea to spend a few minutes brainstorming solutions to the problem before beginning to use the tool such that the outputs of the tool could be compared with the normal brainstorming approach. This was agreed by the researcher (although it is recognised that this was not an effective ‘control’ session when compared to the standards of conventional design experiments). The team were therefore given 10 minutes in which they received no input from the researcher which they used to generate a number of possible solutions.

Both teams were able to successfully complete the tool activity and generate and prioritise a number of possible solutions to their respective problems. There was not time within the session to agree follow-up actions but these were completed by the eco-design facilitators after the sessions.

The feedback score from both sessions were positive, with both groups able to ‘agree’ or ‘strongly agree’ that all the requirements had been met with one exception. This was the ‘generates new ideas’ requirement which the reducing energy consumption group decided was only neutral. However, they did note that the tool brought the benefit of adding structure to the process. Significantly, this was the same group that had conducted the brief brainstorming session prior to using the tool. They had subsequently compared the results of the ‘control’ session with the ideas generated when using the tool. Their conclusion was that many of the ideas were similar and that, although there were some new ideas, they were not significantly better than the ideas that had previously been generated. Interestingly, one of the comments made during the feedback session was that 90% of the ideas generated by Out of the Box tool were thought of using normal brainstorming but that that ‘this tool can give you the 10% extra ideas that you might miss’. This however did not convince the group that quality of the output of the tool was significantly better than that of a normal brainstorming session.

In-depth tool feedback interviews were completed with five participants during which the following points were raised regarding the effectiveness of the tool and the customisations made:

- All of the design team interviewees stated that the format of the customised tool was easier to understand and use and that they planned to use the tool in their work in the future.

- Two people felt that the life cycle perspective was less clear in the Out of the Box tool than in the original 9 Windows tool.
- One designer was concerned that in imposing a time limit for each window there was a risk that the design team would focus on quantity rather that quality e.g. simply try to get as many issues listed as possible rather than discussing the important issues in more detail.
- A benefit of using the tool was that it helped to questions assumptions that had been inherited from previous projects.
- A number of possible further improvements were suggested including completing the initial part of the Out of the Box tool analysis individually in preparation for the group workshop.
- One further desired feature of the tool was the ability to apply the tool in different ways such that the outcomes were more focused towards either short-term, incremental innovation concepts or more long-term, radical concepts.
- Whilst applying the tool took longer than a normal brainstorming session, it was felt that taking this extra time was worthwhile during the early stages of a project as it would help to reduce the risk that significant environmental problems were not highlighted.

Another interesting point that emerged from an interview with one of the eco-design facilitators was that he felt that the design teams participation had had a noticeable effect on their interest and motivation for eco-innovation and eco-design. Furthermore, members of the design team had approached him after the completion of the workshops to encourage him to submit ‘research charters’ (requests for funding for R&D projects) for two of the ideas that had been generated from the tool application workshops.

Based on the feedback results and comments along with the comments from the in-depth interviews, it is concluded that the customisation of the 9 Windows tool at Medipro was successful. Furthermore, it is concluded that the tool introduction process followed was responsible at least in part for generating ‘buy-in’ to eco-innovation tools amongst the design team.

6.6.4 Effectiveness of tool customisations at Intelliprod

The 9 Windows and Sustainable Final Result tools were applied during the first week of activities at Intelliprod. The performance gaps and the subsequent tool customisations for both of these tools were discussed in detail in Section 6.6.2 and so will not be repeated here.

A total of three sessions were completed with these tools during the second week of activities, two sessions using what was by then called the ‘5 Windows tool’ and one session with the ‘Ideal Final Result’ (IFR) tool. It is not possible to provide any detail about the specific briefs tackled within the sessions for confidentiality reasons other than to say that they all considered energy efficiency of a domestic product. One other general point was that the project briefs at Intelliprod were focused towards the creation of new product concepts unlike the project briefs at companies A and B which had been focused on improving existing products. In all of the sessions the participants were successfully able to complete the tool activities, generate ideas for new product concepts and prioritise those ideas for follow-up work.

The feedback score for the 5 Windows tool were reasonably consistent across the two sessions (which involved different participants) and were generally positive. Both teams gave a neutral score for the requirement ‘Time efficient’ because the sessions ran over two hours but they felt that with more practice and strong time keeping this requirement might be met. One small discrepancy between the teams was that the first team strongly agreed that the tool met the requirement of delivering ‘Value to the business’ whereas the second team gave a neutral response. Reviewing the transcript from the second session it was noted that there was possibly a need for more stimulus to help idea generation. The participants felt that with the same group of people applying the tool on a regular basis with the same collective knowledge base, they may not be able to break away from existing ways of thinking. As one designer put it: ‘you are limited by the fish in the pond’. Both teams were able to strongly agree that the 5 Windows tool was ‘Easy to learn and use’. This represented a significant improvement over the original 9 Windows tool.

The feedback for the IFR tool was mixed, with negative feedback for the time efficiency, and marketing requirements. However, it was noted that the tool was more relevant for helping to shape the company’s product strategy. Applied for this type of strategic purpose, it was felt that a longer session would be required and justified. There was also a neutral score for the requirement ‘Finding the right focus’ which asked if the tool had helped to consider the life cycle of the product and select an appropriate issue to focus on. This unfulfilled requirement was not seen as a major problem as the conclusion from the participants’ discussion was that the energy consumption during the use phase was very likely to be the most significant environmental impact of the company’s products for the foreseeable future. The remainder of the feedback was positive with the comments suggesting that the tool was easy to learn and use and brought the value of pulling together different trains of thought.

During the in-depth tool feedback interview the following points were raised regarding the effectiveness of the tool and the customisations made:

- Of the eight workshop participants interviewed, all eight said that they could see themselves using one or both of the eco-innovation tools in their work in the future.

- Four participants said that they would be happy to lead sessions in the future and described some minor modifications they might make to the tools. This suggests that the tools had good ‘buy-in’ from the participants.
- When interviewing the Innovation Director and NPD Manager, they confirmed that they viewed the IFR tool as a more strategy guiding tool and would try to apply it in that capacity in the future. They were also satisfied that both tools could be used for both normal innovation projects as well as eco-innovation.
- One designer stated that they had struggled to understand how to apply the 9 Windows tool but had fully understood the customised 5 Windows tool.

Based on the feedback results and comments along with the comments from the in-depth interviews, it is concluded that the customisation of the 9 Windows tool and the SFR tools were successful. The success of the SFR tool must be qualified by noting that it was only successful as a tool for guiding company product strategy.

6.6.5 Effectiveness of tool customisations at Aquaplus

During the first week of the workshop sessions at Aquaplus two tools were trialled: the Sustainable Final Result and BEC Diagram tools. At the end of that week, the research coordinator commented that some of the outputs of the tools had remained at a very conceptual level and that feedback from both participants and the management suggested that they would like to be able to look at more specific, technical issues. It was in response to this request that it was decided to introduce the 9 Windows tool during the second week of activities.

The major weaknesses of the tools and the corresponding tool customisations made are summarised in Table 6.15.

In total three tool workshops were conducted during the second week, one session with each of the tools. The workshops briefs once again focused on specific issues such as the reduction of materials usage in sub-systems and responsible materials management for components. In each workshop, the tools were introduced, for participants that had not yet seen them, and the tool customisations were explained. One important difference in the way the BEC Diagram session was conducted was that to save time when completing the initial analysis, the group was split in two with half of the group working on the product life cycle ‘prior to the point of sale’ and the other half considering the product life cycle ‘after the point of sale’.

In terms of outcomes, the 6 Windows tool session was the most productive with a total 24 product improvement concepts generated for the two main problems considered. This was followed by the BEC Diagram which generated 15 product improvement concepts, several

Tool	Weaknesses	Customisation
BEC Diagram	• Does not explicitly encourage consideration of the product life cycle. • Tended to highlight known conflicts and opportunities. • Does not help to evaluate ideas.	• Have two BEC Diagrams, one for each half of the product life cycle. • Use of TRIZ 'Inventive principles' to resolve conflicts. • Use 'Eco-innovation idea evaluation form'.
SFR	• Attempting to simultaneously follow multiple lines of thought confusing • Need more help to guide through structured thinking questions • Does not help to evaluate ideas	• Use the MET Matrix to establish the environmental focal issue . • Use separate worksheets to work through one line of thinking at a time. • More relevant structured thinking questions examples provided. • Use 'Eco-innovation idea evaluation form'.
9 Windows	Not trialled in week 1	• Reduce to six windows. • Time limit of 4 mins per window. • Pre-specify window titles. • Use 6 Windows die. • Use of the 'Eco-innovation idea evaluation form'.

Table 6.15: The weakness of the tools trialled at Aquaplus and the customisations made

of which were considered to be very worthwhile pursuing according to the Product Manager who was present. Finally, the SFR tool session considered two key problems and generated a total of 12 possible courses of action to resolve the issues.

Reviewing the feedback, first of all for the BEC Diagram tool, the team 'agreed' or 'strongly agreed' that the tool had met all the requirements with the exception of the 'Time efficient' requirement which received a 'strongly disagree' response. Interestingly none of the tools met the 'Time efficiency' requirement but in every case, it was felt that this was not a problem as the participants suggested that these type of early-stage activities merited spending a reasonable amount of time on. This result calls into question the relevance or the time efficiency requirement. This issue will be discussed further in the final section of this chapter.

Other important comments about the BEC Diagram tool was that although the tool was generally easy to apply, the group had found using the TRIZ inventive principles difficult. This was perhaps because the inventive principles are a major innovation tool in their own right and therefore require a more comprehensive introduction to their usage. With regard to the 'Green issues' requirement, it was felt that a minor weakness of the tool was that it did not provide any detailed suggestions as to the types of environmental impact that should be considered. It therefore relies on the participants having some knowledge of environmental issues and how they relate to the product. Finally, it was suggested that the tool was more useful for helping with product strategy than as a detailed idea generation or problem solving tool that could be used during a project. As one participant put it: ‘projects would emanate from it rather than it benefiting a project that’s already running or just about to start’. It was therefore concluded that it might be used during the annual NPD review in which senior management decide on the types of project to be conducted during the coming year.

Considering next the SFR tool, the feedback here was slightly more mixed with the team unconvinced that the tool helped to consider marketing aspects, as well as the aforementioned problem with time efficiency. A neutral score was given for the ‘Easy to learn, use and understand’ requirement because the group felt that somebody with considerable experience of using the tool would always be required to help guide the development of the initial SFR statement. The group ‘strongly agreed’ that the tool helped to consider ‘Green issues’ and from the audio transcript it was explained that this was mainly due to the MET matrix part of the activity. They also ‘strongly agreed’ that the tool could be used during the early phases of a project.

Finally, for the 6 Windows tool the feedback was mostly neutral with the team not sure if using the tool had generated better ideas than could have been thought of using a normal brainstorming session. Neutral scores were also given for the ‘Marketing aspects’ and ‘Early phases’ requirements, although for the latter the audio transcript suggests that this score was given because the group could not see the tool being used within a conventional NPD project whereas they could imagine it being used in radical innovation projects were the design team would have more freedom in defining the scope of the project and the issues tackled. This finding suggests that some further clarification of the requirement may have been useful. The team were able to ‘agree’ that the tool met the ‘Easy to learn, use and understand’ and the ‘Green issues’ requirements. Furthermore, it was noted by one participant, who had attended the one-day workshop, that the customisations had ‘definitely made the tool a bit more accessible’.

During the in-depth tool feedback interview the following points were raised regarding the effectiveness of the tool and the customisations made:

- Of the 6 design team members interviewed, all six stated that they planned to use the tools in their work in the future. However, it was noted in several cases that whether or not they did get to use the tools again would depend on senior management agreement.
- The BEC Diagram tool was found to be useful for encouraging engineers and designers to think about marketing aspects.

- However, the BEC Diagram was criticised for not emphasising the product life cycle sufficiently. This was possibly due to the fact that the group was split into two and so did not get sufficient time to consider both halves of the work completed which together covered the entire product life cycle.
- There was a concern that within the BEC Diagram tool the same TRIZ inventive principles would be suggested on a regular basis and that their effectiveness as a stimulus would rapidly diminish.
- The SFR tool was still considered difficult to use because the design team were still unsure how to formulate the SFR statement which is the a pivotal step in the process. The tool was also criticised for not providing sufficiently detailed or tangible outcomes.
- The design team were keen to use the tools for normal innovation projects and problem solving as well as for eco-innovation projects.
- Suggestions for further improvements to the tools and the workshop format were made by several members of the design team. These included: pre-preparing the SFR statement; adding ‘R&D requirement’ as an additional requirement within the Eco-innovation Idea Evaluation Form; and spending more time applying the tools but splitting the time over two sessions during one day.
- The Eco-innovation Idea Evaluation forms that were used in all of the sessions were considered a useful way of evaluating and prioritising ideas as well as a prompt to consider the business case for pursuing an idea.

Based on the feedback results and comments along with the comments from the in-depth interviews, it is concluded that the customisation of the 9 Windows tool and the BEC Diagram were successful. The customisation of the SFR tool was considered to be unsuccessful because of the difficulty in generating an appropriate SFR statement and the apparent inability of the tool to produce sufficiently detailed ideas or product concepts. The 9 Windows tool was considered successful despite quite neutral feedback because it produced a significant number of product concepts and improvement ideas and had potential to be used for normal innovation projects as well as eco-innovation.

6.6.6 Cross-case analysis of the effectiveness of the tool customisations

In this section, cross-case analysis is used to search for further insights into the tool customisation process and why some tools were successful whilst others failed.

Of the eight tools customised for Week 2 activities, six were successful and two were considered to be failures.

Focusing first on these two failures, the 9 Windows failed within MetroTech because it was found to be difficult to use by the design team. However, it was still concluded that the design team at MetroTech was more likely to use the 9 Windows tool than the successfully customised BEC Diagram. This was because there was insufficient management support for eco-innovation within MetroTech whereas the 9 Windows tool performed a more generally applicable problem solving function that could still be used outside of eco-innovation projects.

The Sustainable Final Result tool failed at Aquaplus because the design team were not sufficiently confident in generating appropriate SFR statements without expert support, and because the outputs from the tool were not sufficiently detailed or tangible. Whilst Intelliprod had also noted that the SFR tool was more useful for guiding product strategy decisions, the continuing difficulty in generating SFR statements at Aquaplus meant that the tool struggled to gain any support in this alternative function as a strategic tool.

Considering now what made the tool customisations successful, the first noticeable trend was that the customisations suggested by the design team themselves were generally effective. However, it should be noted that even when the customisations had some beneficial effect, the tool was not guaranteed to be successful overall. This was the case with the SFR tool at Aquaplus in which the ‘interface’ of the tool was changed to encourage the group to consider just one line of thinking at a time. Whilst the customisation effectively achieved its aim, it did not help with the other more significant problems with the tool discussed previously and hence overall the tool was considered a failure. It is therefore concluded that the design team can be a useful source of tool customisation ideas but that the overall success of the tool can still depend on other factors.

Another noteworthy observation was the desire to use the tools for normal innovation projects as well as eco-innovation. This trend was witnessed at all of the four companies but was most explicit at Intelliprod where the management team requested that the names of the tools be changed so as to not pigeon hole them as purely eco-innovation tools. There were two reasons given by the management team for this request. First, they wanted to get more value from the tools and increasing their scope of application was a good way of doing this. Secondly, they saw eco-innovation as just a small sub-section of their wider innovation activities. They therefore wanted to reinforce the ‘culture of innovation’ within the company through the use of these tools.

Amongst design teams from the other companies, the main reason for wanting to use the eco-innovation tools for normal innovation activities was to improve the ratio of the benefit derived from the tools to the time and effort spent learning to use them. This finding shares similarities with the ‘Trojan Horse’ approach to implementing eco-design tools proposed by Reyes (2009). She suggests that new tools should be introduced into a company in the form of a tool for conventional design activities. It is then slowly customised, through co-development with the design team, to incorporate environmental considerations. In this research, the opposite process occurred (variations of eco-tools were developed to reduce rather than enhance the environmental focus) but the end result was the same: the tool has more value for the company because it can be used for both normal and eco-innovation projects.

Related to the previous point, it was noticed that the design teams generally favoured tools that produced more detailed, tangible outcomes. The 9 Windows tool was particularly effective at this, which perhaps explains why it was the only tool to be applied in all four companies. Overall then, it would seem that the design teams sought tools that maximised the benefit to their own work by favouring tools that produced more detailed and tangible outcomes and that could be applied to normal innovation projects as well as eco-innovation.

Interestingly, it was also found within both the one-day workshops and the tool introduction studies that the design team did not like the more strategy-focused tools, such as the Future Scenarios and SFR tools because they did not feel that they were responsible for this type of strategy-guiding activity. This is an important finding for eco-innovation scholars as several authors have highlighted the need for eco-design and eco-innovation activities to be strongly linked to the company strategy (Le Pochat et al., 2007, Olundh, 2006, Ritzén, 2000, Simon et al., 2000). If operational-level staff feel that it is not part of their role to be involved in the application of strategic tools then it would suggest that the interaction and communication with respect to strategic issues is, at best, one-sided. Olundh (2006) has concluded that two-way interaction between senior management and design teams, a shown in Figure 6.18, is important for eco-innovation because:

- strategic-level activities such as portfolio management, product planning and the setting of environmental targets will need to be informed by the knowledge, ideas and insights available within the design team; and,
- strategic guidance, decisions and targets must be fed down to the design team to inform the product development activities.

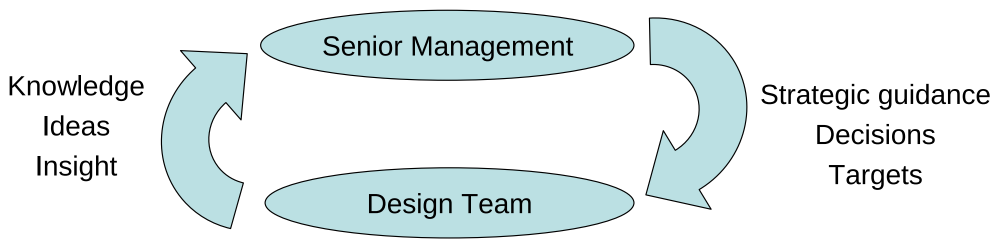

Figure 6.18: Schematic showing the interaction that must take place between senior management and the design team

The application of strategic tools such as Future Scenarios would seem to be an excellent way to increase interaction between the design team and senior management as they can act as a common framework which should facilitate communication whilst potentially helping to tap into the latent knowledge and ideas embedded within the organisation. There are of course different views on how company strategy should be formulated, but the implication for developers of strategy-level eco-innovation tools is that they must be aware of who is involved in strategy development within a particular company and test the tools with those people.

Customising the tools to the design teams' requirements was made more difficult by some of the apparent inconsistencies in their requirements over time. The most noticeable example of this was at Aquaplus were time efficiency was found to be an important requirement for the eco-innovation tools from the Week 1 interviews. However, when all of the Week 2 sessions went beyond two hours, none of the groups felt that this was a major problem. There were even suggestions that the application of the tool should be given more time, split over two sessions. This was not the only example of this type of inconsistency. It is believed that one of the causes of these inconsistencies is that eco-innovation was a new type of activity for the vast majority of the design team members. Therefore their understanding of their requirements for an eco-innovation tool was not fully developed. It was only when applying the tools to real projects that the design team members began to gain a better understanding of what they required for an eco-innovation tool.

Finally, at the beginning of this section the question was posed, 'Can innovation tools be customised to the eco-innovation requirements of a company?'. Based on the fact that six of the eight tool customisations were successful the answer to this question is yes. However, it would seem that customising tools to design team requirements does not guarantee successful adoption of a tool, as was demonstrated by the case of the BEC Diagram tool at MetroTech. This would suggest that there are other important factors that influence the uptake of eco-innovation tools.

In Section 6.2 it was noted that the benchmarking activities had focused on *why* a company had chosen to engage in eco-innovation. Further to this, it is concluded that the tool introduction process was not effective at developing an understanding of *what* functions the company needed the eco-innovation tools to perform. Instead, it focused on *how* the company and the design team needed the tool to perform. This failure was due to the assumption that the companies would easily be able to identify *what* function they needed the tools to perform. Whilst the tools were categorised as being relevant for 'opportunity identification', 'idea selection' or 'problem clarification' activities, it would seem that in some cases the type of tool chosen by the company was not correctly matched to the tool function they required. Some research has been completed which aims to help companies match eco-design tools to the function they require (Ernzer and Birkhofer, 2002). Unfortunately this work is unlikely to be effective for eco-innovation tools as they cover a different range of innovation activities. It is therefore recommended that research be completed to help classify eco-innovation tools and match them to the functional needs of companies, perhaps using a typology of creativity and innovation tools.

Finally, in Chapter 5 it was noted that the search for ‘idea generation’ tools had focused on tools that helped with the specific sub-task of ‘clarifying problems’. The decision to focus on this aspect of idea generation was partly based on the assumption that, if presented with a well-defined problem, design teams in industry would have their own particular methods for generating product concepts. This assumption proved to be incorrect. There was very little evidence of formal creativity methods being used by any of the case-study companies and design team members in several cases suggested that more help with concept generation would have been useful. The eco-innovation toolbox would therefore have benefited from the inclusion of tools that could meet this functional requirement of ‘concept generation support’.

6.6.7 Review of the effectiveness of the tool introduction process

In Section 6.1 a model of the tool introduction process was presented. This model was used to guide the interventions with the participating companies. In this sub-section the effectiveness of that process in producing successful tool customisations is reviewed.

In the previous section it was concluded that it is possible to customise innovation tools to the non-functional requirements of a company. The additional research question was ‘*How* can innovation tools be customised to the eco-innovation requirements of a company?’. To answer this, the following questions must first be answered:

Were the tool customisations successful?

Yes - six out of the eight tool customisations were successful – see Sections 6.6.1.- 6.6.4 for a detailed justification for each case.

Could making no tool customisations or random tool customisations have led to a similar success rate?

Very unlikely - design team members specifically cited the tool customisations made as being the cause of the tool success in many cases.

Could other factors have led to the successful tool customisations?

Very unlikely – the tool customisations were made by the researcher following a systematic process.

Having concluded that the tool customisations were successful, could not have occurred without the intervention, and were the direct result of the process followed, it is now possible to conclude that a reasonable answer to the question: ‘How can innovation tools be customised to the eco-innovation requirements of a company?', is: 'By following the tool introduction process described in Section 6.1'.

There is however one further question which is 'Is the tool introduction process described in Section 6.1 effective at increasing the adoption of eco-innovation tools within industry?'. This question was not posed as one the main research questions because it is not possible to answer it with the data available. To answer this question would require a longitudinal study of a number of companies that had followed the tool introduction process to evaluate the long-term uptake of the tools.

However, it is possible to make two important points about the tool introduction process proposed. First, more emphasis should be placed on understanding the functional requirements of the company and the design team of the eco-innovation tools. This should then be used to match the tool to the functional requirement. Secondly, because eco-innovation is a new activity for most design teams they struggle to understand their non-functional requirements of eco-innovation tools. The best solution to this problem would be to complete a second iteration at attempting to define the design teams' non-functional requirements of the tools once they have had a chance to apply the tools within some real projects.

The tool customisation process could have been improved by adopting a more creative approach to understanding the needs of the design team. The approach used, which involved asking the design team to rate the importance of an existing set of requirements, may well have constrained the discussion and prevented the interviewee from effectively reflecting on their needs for the tools. There are a number of ways of eliciting needs from users (Cross, 2000, Ulrich and Eppinger, 2004). There is therefore potential to apply some of the methods when attempting to understand a design team's needs of eco-innovation tools. This is a task for future work.

6.7 Conclusions

This chapter has considered the research questions 'What are companies' initial reactions to eco-innovation tools?' and 'Can innovation tools be customised to the eco-innovation requirements of a company, and if so, how?'. Section 6.1 introduced the tool introduction process which was used as a model of the interventions with the participating companies. Section 6.2 presented the results of the benchmarking activities and summarised the 'company need' for engaging in eco-innovation activities. Section 6.3 presented the findings from the one-day workshops and answered the first research question by providing insights into the responses of the companies to the eco-innovation tools. Section 6.4 explained how the requirements of the design team were captured through the Week 1 workshops and interviews; compared the design team requirements across the four companies; and explained how the Week 2 tool evaluation requirements were developed.

Section 6.5 detailed the tool customisation strategy and gave detailed examples of how the tools had been customised.

Section 6.6 reviewed the effectiveness of the tool customisations within each of the four companies before using cross-case analysis to search for more general trends. Of the eight tool customisations completed, six were found to be successful and it was found that one of the reasons for the unsuccessful tool customisations was that in at least one case the eco-innovation tool chosen did not match the function required by the company. This led to the general conclusion that more research is required to help classify eco-innovation tools and match them to the functional need of the company. Furthermore, it was concluded that design teams generally favour tools that provide detailed, tangible outcomes and tools that can be used for normal innovation as well as eco-innovation projects because such tools are more closely matched to the functional requirements of staff at this operational level. It was also found that design team staff did not feel that it was their responsibility to apply strategic-level tools such as Future Scenarios and the SFR tool. This may hinder the development of eco-innovation as previous authors suggest that interaction between the operational and strategic levels of a company is important for the success of eco-innovation (Olundh, 2006).

Finally in Section 6.6.6 it was concluded that the tool introduction process had been successful in developing customised tools and was therefore a suitable process to follow for tool introduction. In the next chapter the drivers and barriers for the long-term adoption within each of the case-study companies are presented and discussed.

7 Drivers and barriers for eco-innovation

In this chapter evidence from interviews with designers, design managers, environmental managers and other staff are used to analyse the drivers and barriers for implementing eco-innovation tools. In keeping with the analytical approach described by Eisenhardt (2002), Section 7.1 provides a case-by-case description of the drivers and barriers encountered within each of the four companies that participated in the two-week tool introduction studies. This analysis draws directly on the pool of evidence including interview data, the results of the benchmarking activities, the tool workshop data etc., as shown in Figure 7.1 below. Quotes are used extensively throughout the within-case analysis such that the reader can 'stay close to the data' and judge for themselves the strength of the empirical data supporting the findings. The cases are depicted as cubes within Figure 7.1 to represent the multi-faceted nature of the case studies. Within the case-study analysis, four facets or themes have been chosen for particular attention, these are: 'People', 'Process', 'Context' and 'Tools'. Section 7.2 involves a higher-level, cross-case analysis that aims draw out some of the more significant and generalisable trends across the case studies. Quotes are used more selectively in this section as the analysis builds on the previously established findings from the within-case analysis.

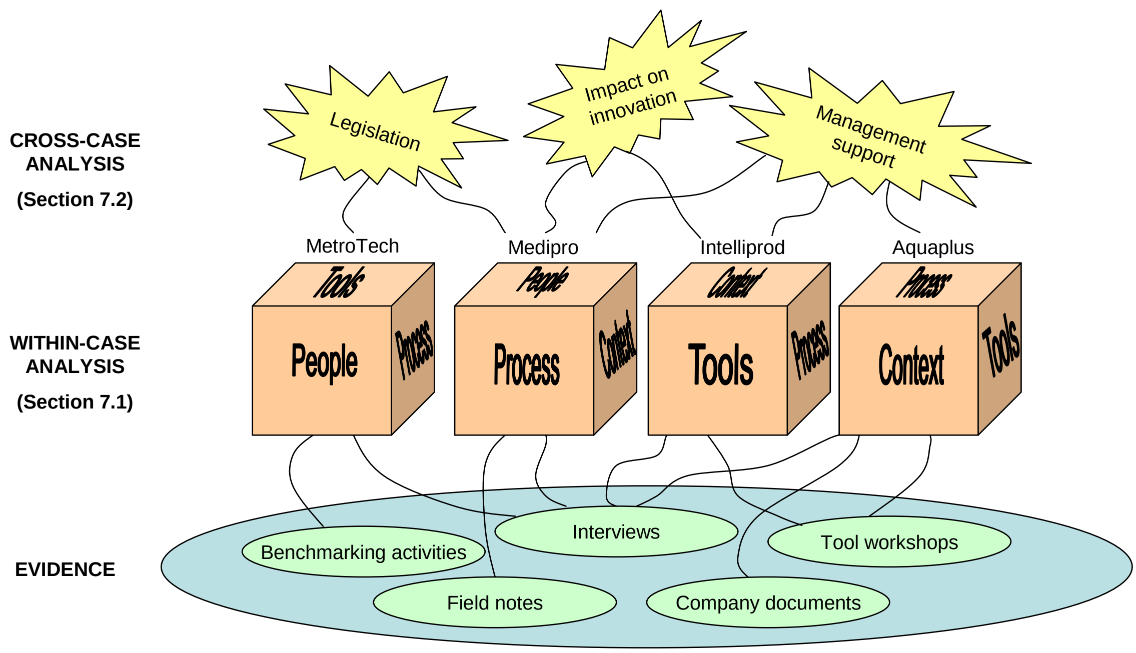

Figure 7.1: Overview of the analytical process used to understand the organizational drivers and barriers for the introduction of eco-innovation tools

Section 7.3 tackles the question 'How do eco-innovation activities relate to existing strategy, innovation and NPD activities?' and presents a model of eco-innovation activities that could help companies with internal communication and in planning the introduction of eco-innovation activities. Section 7.4 summarises the findings and conclusions from the entire chapter.

7.1 Within-case analysis of drivers and barriers

The theoretical framework of force-field analysis (Lewin, 1947), described in Section 2.5.1, was used to structure the analysis of the drivers and barriers for the introduction of eco-innovation tools within each company. This involves examining all of the organisational 'forces' that might support or resist the proposed change and assigning each of them a weighting from one to five (where five represents a very strong force). These forces can be summarised in a force-field analysis diagram. Table 7.1. presents the hypothetical case of a company that is proposing to shift manufacturing to a low-cost country. In this case, the sum of the driving forces is greater than the sum of the barrier forces. Force-field analysis theory would therefore suggest that the proposed change will not work in the current situation and that, if the company still wants to proceed, the management should take action to reduce the strength of the barriers and reinforce the drivers.

Drivers	Strength	Strength	Barriers
Reduced labour costs	4	4	Manufacturing team concerns over ability to maintain product quality.
Culture of 'Top-down' management in low-cost countries.	2	3	Cultural barriers to effective management.
Good levels of staff discipline and motivation in low-cost countries.	2	4	UK staff concerns over job security.
Total	8	11	

Table 7.1: Sample of Force-Field Analysis diagram for the change of 'transferring manufacture to a low-cost country'

For this research, the weightings for each of the forces were completed by the researcher, based on the frequency that an issue was raised by the participants and the level of importance they attributed to the issue. Whilst this was a relatively subjective process, some level of validation did occur as the force-field analysis diagrams were included in the company feedback reports that were reviewed by research coordinator in each company.

To facilitate subsequent cross-case analysis, the drivers and barriers have been further divided into four themes:

- *People* - issues relating to the knowledge or opinions of a specific person or a particular group of people within the organisation.
- *Processes* - issues relating to the ways of working within the organisation. This includes both formally documented processes and the informal processes.
- *Context* - issues relating to occurrences not directly controlled by the design team but which have some relevance for product development activities. Such influences can be

from the external environment of the company e.g. legislation, competitor activity; or internally e.g. corporate strategy, organisational history and culture.

- *Tools* - issues relating to the introduction and use of design and innovation tools. This includes both 'eco' and 'non-eco' tools.

7.1.1 MetroTech

MetroTech design and manufacture low-volume, high-value industrial products.

People-related drivers and barriers for eco-innovation within MetroTech

Within MetroTech the most significant barrier to the long-term adoption of eco-innovation tools was the perceived lack of Board-level support for eco-innovation. It was noted by the research coordinator that although the Board had not offered any explicit support for eco-innovation, they were aware that the company was participating in eco-innovation research and therefore were offering tacit support by allowing this activity to continue. Nonetheless, having more positive, explicit support for eco-innovation activities was seen as being vital for the long-term success of the initiative due to the 'top-down' culture of the organisation:

> *The barrier is definitely a lack of buy-in and strategy from the top. Any initiative that can't find the support from the very top is going to fail at some point.*

(Comment made by an Engineer during an interview)

It was felt that if there was top-level support and encouragement for improving environmental performance, this would soon filter down and result in changes in design activity (such as support for the introduction of eco-innovation tools):

> *But if some big boss in the company says, 'you shall think about the ecological side of the project', then people will tend to do it, but you have to be championed by one of the big bosses.*

(Comment made by a Project Manager during a tool feedback interview)

One barrier to the adoption of eco-innovation tools was that the design team members were aware that, relative to many other types of product, MetroTech's products did not have a significant impact on the environment. This led them to conclude that there was little need to engage in eco-innovation:

> *We make money on having patented technologies and we don't need to sell colossal volume. And similarly most of them are low power technologies as well so when you try and start arguing about life cycle, environmental impact people are just not going to be that convinced*

because those don't have much impact on anything in the grand scheme of things.

(Comment from an Engineer during an interview)

There was however, a small network of staff who were particularly concerned with improving the company's environmental performance. This group had put together an article on the company's existing efforts to improve the environmental performance of its operations for the company news letter e.g. recycling of manufacturing scrap and office waste, the installation of a ground source heat-pump to heat one of the office buildings etc. The research coordinator organised an eco-innovation workshop which introduced them to two of the eco-innovation tools as he felt that by providing this group with the tools, they might be able to apply them in their work, even if there was no formal roll-out of the tools.

One issue that became apparent during the workshop sessions was that the design team were showing signs of frustration at the quality of information being returned to them by the marketing function about user requirements and how requirements tended to change over time, leading to delays in projects and wasted design effort:

Products specs are sometimes 'wooly'… they're desires more than essential. These somehow need to be passed onto the people who are actually designing the product.

(Comment by an Engineer during a tool feedback interview)

Apparently, the company was already aware that requirements capture and management activities were not being performed as effectively and efficiently as they could be:

Something else that [MetroTech] isn't very good at is requirements capture because we've never had to do it. We dream up these things and we impose them upon the market and if you want to buy one then the only place you can get it, because of the way we manage our intellectual property, is from [MetroTech].

(Comment from a Project Manager during an interview)

This is what as a company we struggle with, moving from a customer need to a requirement so that we can then start producing the spec and map that spec to see if we are meeting the customer requirement… I think that is possibly because we are not used to engaging in this process.

(Comment from an Engineering Manager during an interview)

This issue was considered to be a barrier to implementing eco-innovation tools as, according to Koen's model (2001), radical innovation will need to be supported by sophisticated opportunity analysis processes, including the ability to understand and capture customer requirements.

Process-related drivers and barriers for eco-innovation within MetroTech

The lack of environmental criteria within the requirements specification was highlighted by several participants as being a major barrier to the introduction of eco-innovation tools as without such a requirement the engineers can not justify spending time and effort in applying the tools.

> *I can see myself doing that if we are directed, and the way we are going to get directed is by the marketing specification document. If there is something in that marketing specification document that brings up that issue.*

(Comment from an Engineer during a tool feedback interview)

Similarly, project managers recounted that they had not been able to able to incorporate environmental requirements into projects without having a higher level policy document supporting such actions:

> *I've tried to persuade [other project managers] to incorporate RoHS requirements in their projects. They say: 'If you can't get a signed document…we ain't going to do it.'*

(Comment for a Project Manager during a tool feedback interview)

This was considered to be a major barrier to the adoption of eco-innovation tools because, as has previously been stated, if there are no environmental requirements, then there is no justification for spending time and effort trying to improve environmental performance (Luttrop & Lagerstadt 2005)

Context-related drivers and barriers for eco-innovation within MetroTech

Environmental legislation was an important topic at MetroTech at the time of the research. They were in the midst of a long process to become RoHS compliant. The decision to make all products RoHS compliant was a strategic one as only a small percentage of MetroTech's product range fell within the scope of the directive. At the same time, the company was also beginning to understand the possible implications of the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (European Commission, 2006c) and EuP Directives:

> *From the company perspective there is a clear strategy in the sense that we need to comply to RoHS and that is the only thing we are designing for at the moment and that is understood. So, yes we can use the tools to aim*

at RoHS but at the moment we cannot use the tools to aim at WEEE or EuP because we do not understand that at all.

(Comment from a Project Manager during an interview)

The company was therefore keen to explore ways to reduce the cost of complying with these pieces of legislation, and possibly gain some competitive advantage at the same time.

Members of the design team also felt that because of increasing amount of legislation and other types of external driver, the pressure for MetroTech to improve the environmental performance of its products was only likely to increase. For instance, the company had recently received feedback from City analysts that they should be doing more to improve its environmental performance and to communicate this to stakeholders. The company was therefore interested in engaging in activities such as eco-innovation that might help to improve its 'sustainability story'.

Tools-related drivers and barriers for eco-innovation within MetroTech

A number of design team members highlighted barriers relating to the culture of tool usage in NPD activities by MetroTech. Foremost amongst these was a culture of focusing on creative talent rather than relying on innovation tools to foster creativity. Discussing a previous, failed attempt to introduce TRIZ tools, an Engineering Manager made the following comment:

I do encounter the situation that, 'I use my intelligence to solve problems. Somebody else's tools, some other person's way of doing it isn't for me and why should they be better than I am?'…I was surprised by the high degree of response that was along the lines of 'you can't make non-creative people creative.'

(Comment from an Engineering Manager, during an interview)

The same participant went on to suggest that this attitude stemmed from the history of the company:

There's a very fundamental culture in the company that is to do with rejecting other people's ways of doing things. I have to say that that needs to be taken somewhat in context because this is an incredibly successful business that's fundamentally based on people charting their own way. It comes from culture of saying, 'Well we wouldn't be here if we did what everybody else did'.

(Comment from an Engineering Manager, during an interview)

This comment also alludes to the important role that the Founder and CEO played in the companies innovation activities. Over a long career, the CEO had had a significant influence on the development of the metrology industry and was credited with developing a very successful business based on technical excellence and innovation. He had a very strong influence on the technical innovation within the company and was described by one long-standing employee as a ‘prolific innovator’. Much of the culture of focusing on ‘innate’ creative talent and rejecting innovation tools can therefore most likely be attributed to the CEO’s success story.

This aspect of the company culture can also help to explain the previously mentioned problems that MetroTech was facing with requirements capture and the poor relationship between the Marketing and Engineering functions. As the company had a very successful history of ‘technology-push’ innovation, it had become increasingly confident in its ability to deliver excellent solutions. This had led to less emphasis being placed on capturing user requirements and, to some extent, a belief that the company understood their customers’ requirements better than they did:

> *We will often, very early in the project, say that ‘This needs to be one micron repeatability accuracy.’ That’s because we have in our head a solution to the customer’s problem, not because the customer says I want one micron repeatability…Again, in the context of some of the things I’ve said about the success of company, that may well be right - we may well see what the customer needs more clearly than he does.*

(Comment from an Engineering Manager during an interview)

Also, if the company knows what the customer needs more clearly than he does, then there is little need for marketing staff to spend time and resource trying to capture user requirements and less reason to maintain a good working relationship between the marketing and engineering functions.

All of this helps to explain why innovation tools, and particularly front end of innovation tools that focus on understanding user requirements, were not commonly used and faced resistance within MetroTech. Hence, for this reason, it was concluded that eco-innovation tools would face resistance from this aspect of the company culture.

In light of the previous discussion, it is unsurprising that there was evidence found to suggest that the company did not have an effective process for implementing new tools. First, there was the failed attempt to implement TRIZ tools mentioned previously. Secondly, the following comments from a Project Manager suggest that tools are not becoming culturally embedded within the company:

Ideally [innovation tools] are sort of second nature, they're part of the company culture - which they're not at the moment. I don't believe they're embedded enough in the company culture.

(Comment made by a Project Manager during an interview)

One of the problems raised when discussing the introduction of other types of design tool (in this case 'Six Sigma') was the lack of time available to apply the tool to real projects following a training course:

I guess what I found the biggest problem to learning these new techniques is finding ways to apply it in an appropriate time frame to your job such that you don't forget…You come to apply it and you've forgotten how to do it and you have to go back and get the course notes out and it slows down that whole process.

(Comment made by a Project Manager during an interview)

Furthermore, there was no evidence of any follow-up activities for the recent tool introduction activities. However, it was suggested that there were company experts for tools such as Six Sigma who could be called upon for assistance.

The final general barrier to tool usage mentioned by the design team was the time, effort and amount of persuasion it would require to organise a group session to apply eco-innovation tools:

I can't really imagine sitting everybody down in a big room and making them spend an hour or two just thinking about the ecological side of the project.

(Comment from a Project Manager during a tool feedback interview)

There were a number of positive aspects of the tool introduction that will act as drivers for adoption. The primary benefit of using the eco-innovation tools was that they helped to encourage collaboration and communication across company functions; and they were seen as contributing to the design team's more general problem-solving ability, as discussed in Chapter 6.

	Drivers	Strength	Strength	Barriers	
People	Engineers desire to have more contact with end-users/ customers.	1	5	Lack of Board-level commitment to reducing environmental impacts.	People
	Small network of 'environmentally motivated' staff.	1	2	Perception that MetroTech products do not have a significant negative environmental impact.	
			2	Poor requirement capture and management processes.	
Process			4	Absence of environmental criteria in requirements specification.	Process
Context	Likely forthcoming requirements from REACH and EuP Directives.	2			Context
	Pressure to improve environmental performance from city analysts.	1			
Tools	Ability of the eco-innovation tools to improve general problem-solving/creativity.	1	1	MetroTech do not have an effective tool introduction process.	Tools
			1	Little management support or 'culture' of tool usage.	
			1	Time required for organizing sessions and applying tools.	
	Total FOR change	6	16	**Total AGAINST change**	

N.B. Strength scale: 1 – Minor impact on planned change, 5 – Major impact on planned change

Table 7.2: Force-field analysis diagram for the introduction of eco-innovation tools at MetroTech

From the force-field analysis (Table 7.2) we can see that within MetroTech the forces against change outweigh the forces for change by 6 to 16. This suggests that the proposed change is unlikely to be successfully adopted. A number of recommendations were made to MetroTech to encourage a more favourable Force Field. The top three recommendations were:

1. To increase Board-level commitment and support for reducing the environmental impacts of Renishaw's activities the business case for action needs to be clearly presented. Arguments supporting the case include; the possibility of improving innovation and product performance through the application of eco-innovation tools; the potential marketing benefits, including the ability to present a strong range of environmental actions to city analysts; and the potential cost-savings both direct (materials and energy saving) and indirect (reduced cost of compliance with forthcoming legislation).
2. Evaluate the possibility of including specific and measurable environmental requirements in the requirements specification with New Product Development stakeholders (e.g. 10% reduction in product mass/energy use compared to previous model).
3. Develop a company-wide, systematic approach to introducing innovation tools including appropriate planning, introduction and follow-up strategies.

7.1.2 Medipro

Medipro is a large multi-national company that design and manufacture complex, very high value healthcare products.

People-related drivers and barriers for eco-innovation within Medipro

The primary barrier to adoption of eco-innovation encountered at Medipro was the lack of interest in the environmental performance of the products shown by Medipro's customers. This had been reinforced by a piece of market research that the company had undertaken prior to participation in the research that had found that top customer priorities: cost, clinical performance (quality of images), and throughput capacity. Environmental performance was not considered a significant requirement. This was seen by a number of participants as being a barrier to eco-innovation as it undermined the business case for improving the environmental performance of the company's products.

An additional effect of this issue was that the business unit marketing function showed little interest in marketing the environmental benefits of the company's products. This piece of market research was offered as justification for this position by the marketing staff (who declined an invitation to participate in these eco-innovation research workshops). This lack of interest in environmental performance was cited by the Eco-design Facilitators and the Eco-design and Sustainability Manager as a barrier to eco-innovation. They felt that it was the role of marketing to inform and sensitise customers to the environmental aspects of their products:

> *Marketing is not on board and that's because our customers are not asking [about environmental issues]…. That's the trick in the store; when you are not mentioning, they are not asking - the discussions simply don't start.*

(Comment made by the Eco-design and Sustainability Manager during an interview)

To try and stimulate more interest within the business unit marketing function for environmental issues, the Eco-design and Sustainability Manager had given them a significant role within the latest version of the company's eco-design process[6]. Gaining buy-in from the business unit marketing function was at the time seen as a priority issue for the development of eco-innovation activities by the Eco-design Facilitators.

[6] The researcher was provided with a copy of the company's eco-design process document but unfortunately no part of this document can be reproduced within this dissertation as it is company confidential.

A small positive aspect from this market research was that within the top priority issue of cost, it was found that there was increased interest in achieving lower running costs. This was attributed to changes in the United States healthcare system which had recently introduced dramatic reductions in the standard prices paid to clinics for performing scans, X-rays etc. For this type of equipment, one of the major contributors to running costs is the energy consumption. Indirectly, this could act as a driver for eco-innovation by focussing innovation effort on reducing in-use energy consumption. At the same time, it was noted that most customers would not be willing to pay a premium in the initial purchase price, even if the total cost of ownership was lower. It was simply that, if two products were otherwise identical, the running costs would then become a product differentiator.

The final barrier to implementing eco-innovation tools under the ‘people’ theme was the lack of middle management support for environmental issues. These managers were more concerned with delivering a safe product, on time and within budget and so had little time to support environmental issues:

> *I think for the tool, it is very important that it has recognition of the management. I do not know if [the Middle Managers] really know that we’re thinking about these things. Maybe, if [the Eco-design Facilitator] writes a charter and [the Middle Manager] has to sign it off it gets more attention, because with these kind of topics, nobody is really anxious for it at the moment…this is just one of the many things you have to do.*

(Comment by an Engineer during a tool feedback interview)

This was considered a fairly significant barrier as this level of management held significant influence over how design resource was applied and hence gaining their approval would be crucial to the successful adoption of eco-innovation tools.

Moving on to the drivers for eco-innovation tool adoption, it was interesting to find that, in contrast to the previous issue of lack of middle management support, there was support for environmental issues from board level of management. Both the CEO and the Director of Sustainability were mentioned by participants as being important drivers for eco-innovation:

> *Another driver is enthusiastic people in your organisation. That drives the work; you need those guys, but also it helps a lot when your CEO is very enthusiastic.*

(Comment made by the Eco-design and Sustainability Manager during an interview)

The Director of Sustainability was credited with implementing a comprehensive system for reviewing the environmental performance of each business unit and their suppliers.

Further evidence of the support offered by Board were the corporate-level targets and investments being made for improving environmental performance, which are discussed under the *Context* theme.

Another significant driving force was the existence of the Eco-design Facilitators within the company. Within the case-study business unit, there were two people performing this role for one day per week alongside their normal engineering design and research roles. The main responsibilities of the Eco-design Facilitators were:

- *Education* - organising training for engineers on eco-design, the use of LCA software and the company eco-design process.
- *Support* - working with project managers to set environmental targets for projects and to support the performance of environmental assessments.
- *Advocacy* - communicating the company's achievements in eco-design and encouraging other design teams to follow suit.

The Eco-design Facilitators were also seen as having a very direct and important role in supporting adoption of the eco-innovation tools within the company. This role was recognised by the design team, as shown by the following comment:

> *I think you really need support from [the Eco-design Facilitators]. If [the Eco-design Facilitators] do not deploy it, you will use it once and maybe a half year from now we will use it the second time and then it will be forgotten.*

(Comment from an Engineer during a tool feedback interview)

The final driving force under the People theme was the general motivation of the design team to support eco-innovation activities. This support was based on an understanding that eco-design and eco-innovation can have net benefits for the company:

> *What we've found in practice is that most of the time you can combine the profits from being more sustainable. A design which takes care for the sustainability in general always is a design that's cost-effective and commercially attractive to sell.*

(Comment from an Engineer during a tool feedback interview)

Having people that believe in the benefits of eco-innovation and, more generally, have a genuine interest in sustainable development was an important issue according to one Engineer:

> *If you [apply eco-innovation tools] with people who are really concerned about sustainability and want to achieve this goal, then it's worthwhile. If*

you do it because the boss tells you, you have to take care for sustainability in your design process, and you are not motivated, well, then it's just a matter of filling in the 9 Windows and the outcome is useless.

(Comment from an Engineer during a tool feedback interview)

Process-related drivers and barriers for eco-innovation within Medipro

There were two process-related barriers to the adoption of eco-innovation tools at Medipro. First, during some of the eco-innovation tool application workshops it became apparent that a number of the design team did not have a good understanding of which systems or components within their products made the most significant contribution to its overall environmental impact. This led to some debate and discussion as to whether the specific environmental issue selected (chosen by the Eco-design Facilitators prior to the workshop) was the best issue to focus on. The company does have a strategy for selecting eco-design issues to focus on. It had been decided at a corporate level to focus on six broad environmental aspects of their products, which were:

- hazardous substances
- energy efficiency
- weight
- packaging
- recycling and disposal
- lifetime reliability.

So whilst the design team were able to agree on the most important environmental aspect of the product (in this case energy efficiency), there were still delays in the workshop session due to the difficulty of establishing a consensus on what specific systems within the product should be prioritised. It would have been preferable to have had a simple set of 'static' rules to dictate which systems to focus for each type of product. This was not possible because the most energy intensive or inefficient sub-system of a product will vary over time as technology and the feature set changes. However, it was suggested that one possible solution would have been to have presented the results of an LCA from a previous product at the beginning of the session, including a breakdown of the energy consumption by sub-system, such that all participants could evaluate the evidence.

The second barrier identified was a lack of manpower available during NPD projects to work on improving environmental issues:

> *There are a limited number of people involved in a project and they can't do two things at the same time. You have to make choices; sometimes they have to work on sustainability, sometimes they have to hurry up in realising the electrical design. It's a balance of how much time can be spent on what.*

(Comment from an Engineer during a tool feedback interview)

Designers were also concerned that attempting to develop significant innovations with an NPD project would lead to immature technology being incorporated into products without sufficient testing:

> *We need some more time to have as project time, but also more pre-development time to research this. We don't want to introduce new technologies that we have not tested completely in a new product.*

(Comment from an Engineer during a tool feedback interview)

This suggests that it might be more appropriate to conduct eco-innovation activities within an R&D-type project, rather than within the NPD process. This issue is revisited in Section 7.2.3.

But whilst lack of time available to dedicate to environmental issues was noted as a problem by a number of the design team members, it was also suggested in one workshop that spending time on eco-innovation during the very early stages of a product would not be a significant burden as there is less time pressure during those stages. Furthermore, it was noted that by conducting eco-innovation activities, the company were likely to reduce the effort and expense associated with compliance with environmental legislation:

> *The only choice we have in this case is: either we do it now and we are in a more comfortable position; or we don't do it and we have to do it when the law comes and then it will be more expensive.*

(Comment from an Eco-design Facilitator during a Week 2 workshop)

For these reasons, lack of time to apply eco-innovation tools was only considered to be a weak barrier.

The most significant driver was the presence of specific environmental requirements within the product requirements specification. This had only recently been introduced at the time of the research and so there was little evidence of the actual impact on eco-design or eco-innovation performance. It was an issue that the Eco-design Facilitators had spent a long time lobbying the management to introduce. The environmental requirements were set by the Project Manager with assistance from the Eco-design Facilitators. Initially an overall 'budget' was set for the entire product in terms of EcoScan points. This budget was then distributed across the various sub-systems and components such that each designer would be responsible for ensuring that their part of the product met their environmental budget requirement as well as their functional requirements. The significance of this, was that it was effectively an authorisation from senior management for designers to spend time on improving the environmental performance of the product. The Eco-design Facilitators had hoped that this initiative would help to improve the previously highlighted barrier of lack of time. However, there was evidence of some resistance to this from certain designers who saw environmental requirements as yet another hoop to jump through:

> *[The Eco-design Facilitators] would like to make any new project a [Green Product], but I would to do as little design work as possible because I have always the time pressure on the project. Everything that has to be verified and proven I want to avoid.*

(Comment by an Engineer during a Week 2 workshop)

However, in general the introduction of environmental requirements within the requirements specification was felt to be a significant driver for the adoption of eco-innovation tools.

Related to this, another driver was the existence of a company eco-design process. This formal document had recently been reviewed and simplified. It contained detailed descriptions of the stages within the eco-design process which were closely linked to the company's NPD process. Furthermore, the actions required by stakeholders were detailed along with their responsibilities. Finally, the process explained the requirements that must be satisfied for a product if it is to be awarded 'Green Product' status. The Eco-design Facilitator was able to show the researcher documentation from previous projects that proved that the eco-design process had been followed successfully. The benefit of having this eco-design process established (from the perspective of eco-innovation tool introduction) was that it provided a clear framework for environmental-related activities into which the eco-innovation tools could be placed.

A further benefit from the eco-design process was that it mandated the completion of a full LCA for products that were seeking Green Product status. This had led to a significant number of the design team being trained in the use of EcoScan. Those that had not been trained in EcoScan were at least aware of it and had some understanding of what the results meant. Furthermore, the same LCA tool had been used within the company over a number of years which meant that there was a significant number of product LCAs completed which could be used for benchmarking new products. The generally good understanding of LCA principles and tools across the design team and the catalogue of completed LCA studies were considered as drivers for eco-innovation as they would enable the design team to assess the improvements in environmental performance achieved through eco-innovation activities.

The final driver under the 'process' theme was related to the communication of the company's achievements in eco-design and environmental performance. The company communicated their environmental achievements to external stakeholders through a Sustainability Annual Report, through their corporate website and through presentations at academic and industrial conferences delivered by the Eco-design and Sustainability manager. Internally, designers attended an annual training day on eco-design and sustainability and results were also presented at important occasions, as was mentioned previously. In all of these communications, there was a significant amount of detail and content relating to eco-design including examples of Green Products and the improvements achieved. There were also details of the corporation's environmental performance targets and how the company was performing against those targets, some of which are discussed under the 'Context' theme. These significant efforts to communicate eco-design and environmental achievements was considered to be a driving force for eco-innovation tool adoption as it helped to reinforce the culture of valuing environmental performance and possibly served to inspire design teams.

Context-related drivers and barriers for eco-innovation within Medipro

A number of the drivers and barriers raised by the design team were related to supply-chain issues. As mentioned previously, Medipro had put significant effort into managing the environmental impacts of its supply-chain. One of the results of this was that all suppliers had to sign an environmental declaration which committed them to working with Medipro to reduce the environmental impacts of the components they supplied. Despite this sign of positive engagement with suppliers on environmental issues, there were a number of supplier-related barriers.

First, there was the fact that the majority of the product was bought-in. That meant that Medipro had less control over the design of components and possibly less understanding of how they could be improved from an environmental perspective. This was considered a major barrier to eco-innovation as without control over the fundamental technology of the product, technical innovation was more difficult. In particular, the Eco-design Facilitator gave an example of an idea to reduce the energy consumption of the product which had not been implemented because it required running a compressor at a frequency outside of its rated operating range. The supplier would not authorise this and so the idea had to be abandoned.

Secondly, there were a limited number of suppliers available in the market place for some of the core components. This would impact on eco-innovation because it discouraged partnering with those suppliers to innovate, as there was a danger that any resulting innovation would quickly become available to Medipro's competitors, thereby eliminating the competitive advantage of the innovation.

The remainder of the drivers and barriers under the 'context' theme relate to the actions and culture of the wider corporation. The corporation had a culture of good environmental management and corporate responsibility. This was demonstrated by the fact that the company had had an environmental policy in place since 1991 and that improving sustainability performance was one of the corporations seven strategic actions. The researcher attended an eco-design training day at Medipro during which the Eco-design & Sustainability Manager gave a presentation about the corporate view and strategy on environmental sustainability. The clear message from this presentation was that environmental sustainability was both an opportunity and a potential liability for corporate brand value. Evidence was presented from the Dow Jones Sustainability Index to show that the companies with the best sustainability performance had increased their share value significantly, more than their less sustainable peers over the last 10 years. The mounting pressure from NGOs was later discussed with the Eco-design & Sustainability Manager who stated:

> *We are increasingly under attack by NGOs, more so in the consumer market than in healthcare, but we are part of [the corporation], and they focus on chemicals, on substances and on CO2 more and more.*

(Comment by the Eco-design & Sustainability Manager during an interview)

Whether efforts to improve the environmental performance of the corporation were being pursued as a reactive measure to pressure from NGOs or as a proactive measure to increase brand value, the net effect was that environmental sustainability received significant attention at the corporate level. This was also evident in corporate marketing which, unlike the business unit marketing function, made considerable efforts aimed at enhancing brand reputation through demonstrating environmental excellence for both products and operations:

> *That's why we learned to supply eco design and make green products not for our marketing but for the [corporate] policy and branding…It's more for corporate policy and for green image building than direct product marketing.*

(Comment made by an Eco-design Facilitator during an interview)

Further corporate level drivers for eco-innovation included ambitious targets for investment in more sustainable technologies and increasing the percentage of total sales revenue coming from ‘green products’. Such commitments again help to reinforce the culture of taking environmental protection seriously and valuing eco-design and eco-innovation activities.

Tools-related drivers and barriers for eco-innovation within Medipro

The selection and development of new design tools was a well-managed process within Medipro. A committee was in place to approve the funding and manage the process of adopting new design tools. A long-serving Quality and Environmental Manager was able to describe several examples of new tools being adopted within the company including examples of both large scale software projects involving external consultants and smaller scale, in-house tool development projects. Both types of project involved extensive consultation with end users and opportunities for feedback prior to the formal launch of the new tool. After the launch of the tools there were good training programs and on-going support. However, it was noted that the one weakness with the process was that sometimes problems arose several months after the tool had been finalised. This was because it was often only after several months of usage that users began to use the full functionality of the software and began to realise that certain desirable features were missing or not executed in an appropriate manner. This was a useful lesson as it suggests that an additional feedback session should be conducted several months after the introduction of a tool in order to resolve any issues that have become apparent in the intervening period. Overall, the well-managed tool introduction process was felt to be of significant benefit for plans to introduce eco-innovation tools.

As with MetroTech, Medipro used a wide variety of sophisticated design tools like Six Sigma. However, none of the design team mentioned using any formal creativity tools. This lack of experience of using creativity tools was therefore considered to be a barrier to the adoption of eco-innovation tools.

	Drivers	Strength	Strength	Barriers	
People	Eco-design facilitators championing the eco-design process and tools.	2	3	Customers do not appear to have significant interest in environmental performance of the product.	People
	Customers have shown some interest in low-running-cost products (although purchase price still important).	1	2	Business Unit marketing staff have shown little interest in environmental issues.	
	Board-level support for environmental issues.	3	2	Environmental issues a low priority for middle management.	
	Designers generally supportive of eco-design activities.	1			
Process	Inclusion of eco-design targets within project requirement specifications.	3	1	Debate and confusion over the environmental justification for selecting eco-innovation issues to target.	Process
	Successful eco-design process in place.	2	1	Lack of time to apply eco-innovation tools during NPD projects.	
	Widespread understanding and some use amongst designers of LCA software.	2			
	Good reporting of environmental performance both internally and externally and eco-design excellence is recognised through a green products programme.	1			

	Drivers	Strength	Strength	Barriers	
Context	Environmental issues seen as both an opportunity and a risk to corporate brand value (due to negative publicity from NGOs).	2	3	Large percentage of the product is bought-in reducing design control.	Context
	Environmental declaration signed by all suppliers - generally good collaborative relationships with suppliers.	1	1	Limited number of suppliers available for key components.	
	A history and culture of being a responsible business.	1			
	Commitment by Medipro to significantly increase investment in more sustainable technologies.	1			
	Commitment by Medipro to generate an increased percentage of total sales revenue from green products over the coming years.	2			
Tools	Systematic approach to managing the introduction of new tools.	2	1	Lack of experience of using creativity tools.	Tools
	Total drivers	24	14	**Total barriers**	

N.B. Strength scale: 1 – Minor impact on planned change, 5 – Major impact on planned change

Table 7.3: Force-field analysis diagram for the introduction of eco-innovation tools at Intelliprod

From the force-field analysis (Table 7.3), we can see that within Medipro the forces for change outweigh the forces against change by 24 to 16. This suggests that the proposed change is likely to be successfully adopted. Nonetheless, a number of recommendations were made to Medipro to promote the long term success of the eco-innovation tool adoption activity. The top three recommendations were:

1. As customers had shown little interest in the environmental credentials of Medipro’s products it was suggested that marketing staff should instead discuss the life cycle cost savings that are often associated with eco-innovation improvements. This would require marketing staff to educate customers on the benefits of applying life cycle costing approaches and to present the customer with a clear comparison of the life cycle costs of various systems.
2. As the percentage of bought-in components in Medipro products is likely to continue increasing, it is vital that the company build on its experience of collaborating with suppliers when looking for solutions to environmental challenges. Examples of successful collaborations with suppliers, and even competitors, should be recognised and advertised, both internally and externally.
3. An additional feedback session should be conducted several months after the introduction of the tool in order to resolve any issues that have become apparent in the intervening period.

Whilst not discussed at the time, it was subsequently noted that another potentially useful recommendation for Medipro would be to ensure that the eco-innovation tools are introduced within an appropriate project setting. This is because, with a well-established eco-design process in place, there is potential for conflict between the eco-innovation tools which are aiming for radical, step-change improvements, and the eco-design process, which is aiming for more incremental improvements in environmental performance.

7.1.3 Intelliprod

Intelliprod are a medium-sized company that design high-volume, medium-value consumer products.

People-related drivers and barriers for the introduction of eco-innovation tools within Intelliprod

One of the drivers for the introduction of eco-innovation tools within Intelliprod was their Unique Value Proposition (UVP) on environmental sustainability. This had been put in place following a strategic review around 12 months prior to the commencing their participation in the current research. This UVP was strongly supported by the Director of Innovation. Unfortunately, the effect of this driver was undermined by a concern amongst staff members that Intelliprod was trying to sell 'green' products and promote itself as an environmentally sustainable brand without first reviewing and improving the environmental impacts of the day-to-day operations of the company:

> *I think as well we want to have belief in what we stand for as a company, and at the moment we feel a little bit two-faced because we have this UVP [Unique Value Proposition] that says, 'be sustainable', but we're not really behaving quite as we should because we're just fumbling along a little bit.*

(Comment from a Marketing Manager during a tool feedback interview)

> *To be green it needs to be in everything. People with a company car, you've got to have hybrid cars, you cut down, its everything you do.*

(Comment from a different Marketing Manager during a Week 2 workshop)

From this it would seem that staff are struggling to buy-in to the UVP on environmental sustainability when they are not convinced that Intelliprod are taking a holistic and systematic approach to the issue. Nevertheless, there were a large number of 'off-the-record' comments from the design team that suggested that they recognised that Intelliprod's activities have a significant impact on the environment and that they were keen to do what they could to help the company to reduce its impacts. Evidence of the design team's interest and motivation for environmental issues include the ease with which interviews were obtained with staff (total of 14 interviews with 13 different people from non-management roles), and the willingness to contribute to the tool introduction process (see previous chapter). These factors were considered to be a driver for eco-innovation as the majority of staff understood the ecological need to improve the environmental performance of the company and were motivated to take action accordingly.

Process-related drivers and barriers for eco-innovation within Intelliprod

The most frequently mentioned barrier to applying the eco-innovation tools was a lack of time. The following quotes are just a few of the many statements in this vein:

> *Basically I think it needs to be very time efficient because a lot of people are under-resourced so we need to be as efficient as possible regarding time.*

(Comment from a Design Engineer during a tool feedback session)

> *I think it's really important just because the business is very fast-paced; we're all under a lot of time pressure. I really need to get to answers quickly. For example, we're in a brainstorming session here, we might be able to take two to three hours out of somebody's day, but you're pushing it beyond that.*

(Comment from a Marketing Manager during a tool feedback session)

In order to cope with the requirement for very fast lead times, Intelliprod had developed a very time efficient NPD process based around a bespoke piece of project-management software. Unfortunately, some design team members felt that this process had begun to prioritise speed-to-market over the quality of the final product. For instance, as part of the innovation benchmarking activities two Design Engineers were asked the question, ‘Are there processes in place to ensure that a good idea can result in a successful product launch?’; their response was:

> *A product will launch, but not necessarily a successful product. It’s a strong process that can churn out any idea or product.*

(Comment from two Design Engineers from the benchmarking activities)

The reason for the very tight time schedules was indicated by the Engineering Director:

> *One of the difficulties that we have all the time is that we’re a biggish company but we’re a very small company with a very small team. [The design team] is producing 250, 300 new products a year. And so consequently, a lot of the pressures that are on people are about making a new red one or making a new green one; not the consumer wants 250 ml of water at 98 degrees C, let’s brainstorm how we’re going to get that.*

> *Because we have to have a new kettle because [a retailer] wants a new kettle by next Monday.*

(Comment from the Engineering Director during an interview)

The issue of producing a very large range of products is also commented upon by the Innovation Director:

> *We've got to get off this merry-go-round that we're on now which is doing lots of projects that give us medium-value to low-value in the market and we need to do one project that gives us huge value.*

(Comment from the Innovation Director during a Week 2 workshop)

This sentiment is reinforced by the Manufacturing Director who suggests the following solution:

> *I think you need to take the idea generation and the creation of that innovation away from 'today' so that the people that are working on 'today' are concentrating on 'today' and the people that are working on 'tomorrow' are, to an extent, devoid of 'today' – in a little cocoon away from today.*

(Comment from the Engineering Director during an interview)

This issue of how to separate 'today's' product development activities from 'tomorrow's' innovation activities is discussed further in Section 7.2.3.

It is suggested that a lack of detailed and measurable targets for environmental performance at both the company and product level is a major barrier to the adoption of eco-innovation tools.

> *We have this UVP which is to be sustainable but nobody's told us what criteria we have to use. All that I know at the moment is we don't use polystyrene in new products going forward, but I'd really, really love more specific criteria.*

(Comment from a Marketing Manager during a tool feedback session)

Without long-term company targets there is a feeling amongst staff that the current interest in environmental issues may be a temporary 'fad', and without short-term environmental targets for individual projects the design team will inevitably spend more time on other issues where detailed targets have been set.

A concern that was raised repeatedly by designers and marketers was that the company's pursuit of eco-innovation and its UVP on environmental sustainability could have a negative impact on the overall company performance.

I think it's a danger to run [eco-innovation activities] at the beginning of every project, because everything will be eco driven. Which, alright, that is a great direction for the company but that is not the way everything should be run because it is only a small percentage of what people buy into isn't it?

(Comment from a Design Engineer during a tool feedback interview)

Eco-innovate but lets not forget about potential for innovations. They might not have a green message to them but it could be that no one else is doing that and that is great so I would like to see tools not just for eco but general innovation as well.

(Comment from a Marketing Manager during a tool feedback interview)

Hence the feeling is that the pursuit of eco-innovation will divert attention and resource away from 'normal' innovation activities and that this would not be a commercially sound strategy.

Context-related drivers and barriers for eco-innovation within Intelliprod

Considering the wider context of the company's activities, a number of barriers to eco-innovation were noted. First, there was the issue of a lack of 'brainstorming-friendly' office space. This was due to the company being based in temporary offices at the time but it was felt that sitting in a rather stark, half-empty office was not conducive to generating novel ideas, as the following comment indicates:

We haven't got the stimulus or the environment. It's a very young, creative team but an uninnovative environment.

(Comment from a Marketing Manager during a Week 2 workshop)

In a subsequent interview, this same participant reinforced the suggestion that brainstorming meetings required a more stimulating environment, adding that off-site locations would be useful to restrict the normal distractions due to other work tasks. This issue had already been noted by Innovation Director and NPD Manager and they were actively discussing plans for a suitable space within the new offices with staff during the time of the Week 2 activities. The corollary of this finding is that a good 'brainstorming-friendly' office space was something that innovation hubs often spent significant time and effort on creating and maintaining. This suggests that a good brainstorming-friendly office space is important for innovation.

A second barrier to eco-innovation that was raised by the Sales Director was that of supplier power:

> *One of the barriers is controls in [the product]. The control manufacturers dictate the technology and the eco-friendliness of the product, because everybody buys the controls from the same people.*

(Comment made by the Sales Director during an interview)

From Intelliprod's point of view there is little incentive to collaborate with suppliers of 'stock' assemblies such as control units because of the risk that the supplier will offer any resultant innovation to Intelliprod's competitors – thus eliminating any competitive advantage from their innovation efforts. This issue of how to innovate effectively with suppliers has rarely been mentioned in eco-innovation literature but would appear to be an important barrier. This issue is discussed further in the following section.

Another issue that became apparent during the early workshop activities was the lack of knowledge and understanding amongst the design team of the life cycle environmental impacts of their products. For instance, end-of-life disposal and the transport of components and assemblies from China were often mentioned as being significant environmental issue for Intelliprod. In reality, LCA studies of household goods of the type produced by Intelliprod generally show that transportation and end-of-life disposal are minor impacts compared to use phase impacts (Simon, 1996). In fact, because this issue was very relevant for the Week 2 workshops, it was decided to present the design team with a diagram showing the breakdown of the life cycle energy usage of a Intelliprod-type product in order to justify the focus of the Week 2 workshops on use-phase energy consumption. This issue was commented on by the Innovation Director in private conversations and also the Sales Director:

> *I think that probably the biggest barrier would probably be the lack of understanding, the lack of knowledge of the materials… and what is environmentally friendly, sustainable, compared to what isn't. I don't think we have enough understanding in the business.*

(Comment made by a Sales Director during an interview)

The main driver for eco-innovation from the wider company context was the UVP on environmental sustainability, as a key part of the company strategy. This UVP was strongly supported by the Director of Innovation but, as was noted earlier in the discussion of 'People' issues, there were some concerns expressed by design team members about the authenticity and strategic benefit of the UVP. Hence, due to the scepticism amongst the staff, the UVP on environmental sustainability was considered to be a relatively weak driver for eco-innovation.

Drivers for eco-innovation also came from parts of the business not directly involved in New Product Development activities. Speaking to the Operations Manager at the UK assembly facility, it was clear that that part of the business had already made significant progress on improving its environmental performance. The site had reduced its energy consumption by 26% over last three years and had been recognised by the Carbon Trust for this work. These successes have been partly attributed the bottom-up approach to problem solving, using teams of shop-floor staff to spot problems or opportunities for energy-saving and giving them the power to take action. This was felt to be a driver for eco-innovation because it was a good example of environmental performance improvement which also led to cost savings for the company. The Operations Manager also noted that the cost of returned products was becoming increasingly significant for the company. He felt that this represented an interesting opportunity to apply eco-innovation tools to reduce these costs.

Tools-related drivers and barriers for eco-innovation within Intelliprod

In considering the drivers and barriers for eco-innovation with regard to tools, we can divide the issues into those related to Intelliprod’s use of tools in general and those related to the eco-innovation tools themselves. Beginning with Intelliprod’s general use of tools, it was noted by the researcher that there was very little evidence of creativity or analysis tools being used. Design Engineers generally used project-management software, CAD and rendering packages. One other tool that was mentioned frequently was the ‘5 whys?’ tool which was used by the marketing team to try and understand consumer behaviour. However, this appeared to be the extent of creativity tool usage within the company. When staff were asked how brainstorming sessions were conducted the responses suggested that it depended on the person running the session but that there were no formal tools applied. This is suggested as being a barrier to eco-innovation, as introducing formal tools into brainstorming activities is another new aspect to be introduced into the company culture.

Having highlighted the lack of tool use within the company as a barrier, one driver was the motivation of a number of design team members to begin using the tools and to customise them to their personal requirements. For instance, one Design Engineer said that he would use the tool to encourage non-designers to participate in ideation sessions; whilst another said that he would display the completed 5 Windows analysis next to his desk to encourage others to come and discuss the ideas.

Considering now, the issues relating specifically to the eco-innovation tools, one aspect of the tools that the design team did not like was that they felt that they were limited by the knowledge and experience of the session participants i.e. there were no external stimuli. As one Design Engineer put it, ‘You’re limited to the fish in the pond’. The importance of stimuli for creativity has been proven by previous studies (Howard, 2007) and is therefore a potential area of improvement for the eco-innovation tools.

Both of the tools had aspects that the design team found particularly valuable. For the 5 Windows tool, this was the ability to break down a problem in a formal and systematic manner. For the Ideal Final Result tool this was the ability to encourage more long-term, strategic thinking. It is interesting to note that both of these tool benefits were seen as being relevant for normal as well as eco-innovation projects. This is possibly related to the fact that the company does not currently have a strong culture of using formal methods for brainstorming or innovation. Therefore in introducing eco-innovation tools, the company is gaining the additional benefit of tools for normal creativity and innovation. In a company that already had a culture of using formal tools for creativity, this driver might not be so strong.

	Drivers	Strength	Strength	Barriers	
People	Understanding that Intelliprod products have a significant environmental impact.	1	2	Feeling from staff that Intelliprod day-to-day operations should become 'greener' before trying to sell 'green' products.	People
	Desire to contribute to the improvement of the environmental performance of Intelliprod.	1	1	Unclear as to the main environmental impacts of Intelliprod' products.	
			1	Unclear as to how the environmental sustainability UVP translates to their own area of work.	
			1	Concern that environmental performance will be pursued at the cost of more general innovation.	
Process	Strong project management system that could incorporate environmental requirements.	1	3	Strong focus on lead time reduction leaves no time for experimentation or exploratory research for 'tomorrow's' products.	Process
			2	Lack of long-term targets for company or product environmental performance.	
			2	No environmental requirements included in project briefs currently.	
			2	Insufficient time to apply tools during New Product Development projects.	
Context	Environmental sustainability included as a Unique Value Proposition.	1	1	Supplier monopolies on certain sub-assemblies such as switches reduces incentives for innovation.	Context
	High cost of product returns could provide an eco-innovation focus.	1	1	Lack of a 'brainstorming-friendly', stimulating space for ideation.	

	Strong environmental policy and good environmental performance within UK assembly centre.	1			
Tools	Interest in opportunity to apply eco-innovation tools in ‘normal’ innovation projects.	2	1	Little experience of applying formal tools for creativity and innovation.	Tools
	People willing to adopt and customise tools to suit their own needs.	1			
	Total drivers	9	13	**Total barriers**	

N.B. Strength scale: 1 – Minor impact on planned change, 5 – Major impact on planned

Table 7.4: Force-field analysis diagram for the introduction of eco-innovation tools at Intelliprod

From the force-field analysis (Table 7.4), we can see that within Intelliprod the forces against change outweigh the forces for change by 13 to 9. This suggests that the proposed change is unlikely to be successfully adopted. A number of recommendations were made to Intelliprod to encourage a more favourable Force Field. The top three recommendations were:

1. Include environmental requirements in eco-innovation project briefs and manage them through the project management system as per normal product requirements.
2. Set long-term (2-5 year) targets for company and product environmental performance and collect evidence of improvement.
3. Improve staff engagement and understanding of the Unique Value Proposition (UVP) on environmentally sustainability by providing multiple opportunities and mechanisms for them to raise their concerns about environmental issues related to both Intelliprod operations and products, and supporting initiatives for staff to solve these problems themselves.

After the completion of this, more-in-depth review of the case, it became apparent that the issue of separating out ‘today’s’ New Product Development activities and ‘tomorrow’s’ innovation activities should also have been a key recommendation for Intelliprod. Whilst the company ran what it called ‘X-factor’ projects, these involved the same staff as were doing the NPD projects. Hence, there was still a risk of more urgent NPD projects preventing staff from finding time to progress their X-Factor projects.

7.1.4 Aquaplus

Aquaplus are a medium-sized company that design and manufacture showers.

People-related drivers and barriers for eco-innovation within

There was significant employee interest in improving the environmental impact of Aquaplus's activities. This was demonstrated by the large number of people volunteering to participate in the workshop sessions – the Week 1 workshops involved 8 to 11 people in each and the research coordinator had to turn people away due to reaching capacity of the available rooms.

However, there was little consensus as to what types of environmental issue Aquaplus should be focusing on. Surprisingly, the impacts associated with product use (energy and water usage) were mentioned less frequently than issues such as use of materials, use of toxic materials, product end-of-life, waste water from test rigs, packaging waste and transport impacts. This suggests that employees did not have a good understanding of the relative importance of life cycle environmental impacts of Aquaplus' products.

However, there is an alternative explanation for the lack of attention on water and energy usage during the use phase. It was noted by some of the longer-standing employees that Aquaplus had in the past introduced a range of products with reduced water flow rate to try and improve water usage. Unfortunately, this had led to the company losing market share to competitors who began marketing their products on high water usage! It may therefore have been that this negative experience, which was still present within the 'organisational memory', had made design teams cautious about trying to reduce the environmental impacts associated with the product use.

Another key barrier to the adoption of eco-innovation tools lack of direct interaction between designers and end-users. This was a source of frustration amongst some of the design team members as one industrial designer describes here:

> *We are led to believe that our market place is so…I don't know, 'constant'. It is hard to really deviate. We don't do any pilot products to test the water, so we're denied understanding whether people will accept anything else that's different; simply because we cannot afford to not sell anything.*

(Comment from and Industrial Designer during a tool feedback interview)

One consequence of this was that it was difficult for anyone to challenge the widely held belief in the company that users would not risk sacrificing a 'quality shower experience' in favour of products that might help to reduce water or energy consumption.

The root cause of the lack of interaction with end users appears to have been the need to satisfy the requirements of the retailers and the CEO of Aquaplus' corporate owner. The requirements of these stakeholders appeared to represent strong idea filters, separating the design team from the end-user. Evidence of this can be seen in the NPD process described by design engineers during the benchmarking activities, the first part of which is shown in Figure 7.2.

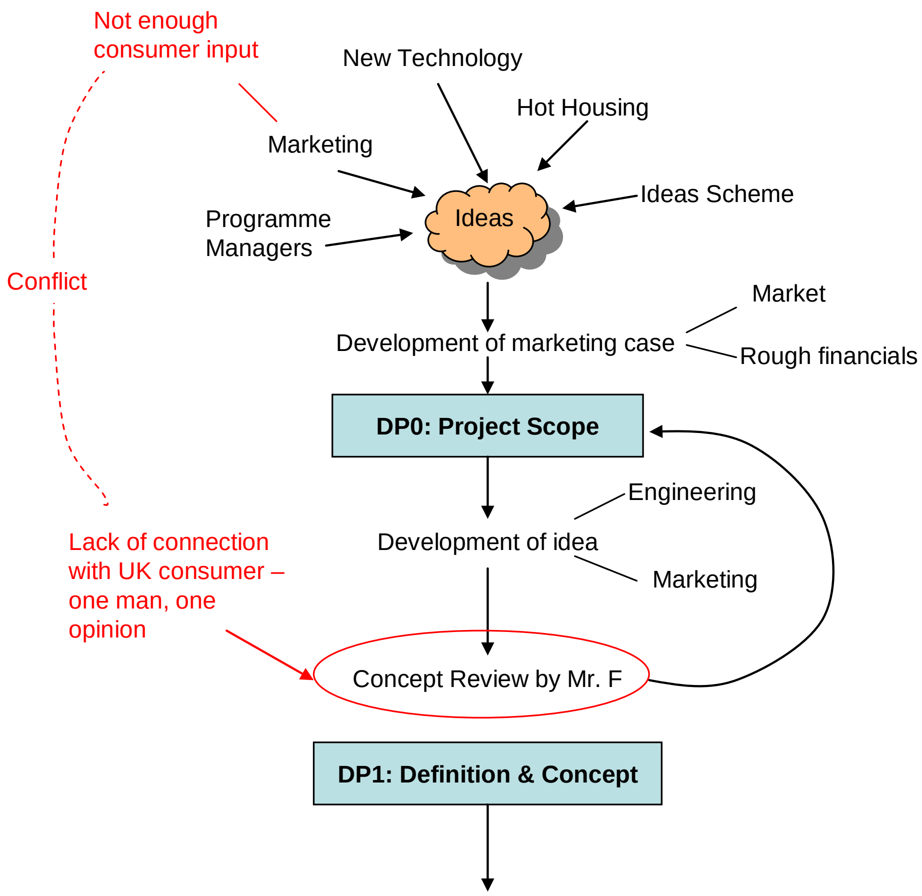

Figure 7.2: Summary of the early stages of the innovation process at Aquaplus

Between the launch of a project and the writing of the formal requirements specification there is a 'Concept Review' by Mr F. This unofficial stage gate was highlighted (in red) as a problem by the participants, adding the note 'Lack of connection with UK consumer – one man, one opinion'. The participants felt that this created a conflict with their desire to increase the level of end-user input into their innovation activities because they had to focus on Mr F's preferences rather than the end-users'.

Interestingly, within the design offices the researcher observed a prominently displayed poster which described the four core competencies of Aquaplus's corporate owners. One of these core competencies was entitled 'Focus on the end customer' and was explained as follows:

Make the consumer, specifier or guest and their needs (as opposed to an intermediary) the primary focus of one's feedback, analysis, and action.

(Comment from a poster explaining Aquaplus's corporate owner's core competencies)

From this, it would seem that there was a conflict between what Schein (2004) would describe as the 'espoused values' and the 'underlying assumptions and values' of the organisational culture. Espoused values are what the organisation *describes* itself as working and operating. This is shown in company mission statements and official procedure/policy documents. In this case, the espoused value is to focus on the needs of the consumer/end user rather than any intermediaries. Underlying assumptions and values dictate how the organisation works and operates *in reality*. This aspect of the organisational culture is difficult to discern, as it occurs at a largely subconscious level; it is simply 'the way things are done around here', the 'unwritten rules'. In this case, unwritten rule was that Mr F. reviewed all product concepts personally, and that his opinion was final when deciding whether or not to progress a concept. Whilst this conflict was apparent to the design team, there was no obvious way to introduce more consumer input without appearing to undermine Mr F's authority and judgement.

The final issue under the 'people' theme was that designers and engineers were concerned that Aquaplus has little knowledge of, or influence over, manufacturing activities that take place in the People's Republic of China. The perception was that suppliers in this region will not be attaining the same standards of pollution control and waste minimisation as those achieved in the UK-based manufacturing operations as the following quote demonstrates:

Plus personally I am pretty uncomfortable with the fact that we do a lot of manufacturing in China where we don't think to care about what we do with things…I know we can ask or we can make our choice of the companies out there that we use, but their practices and processes are going to be not as mature or as advanced as ours.

(Comment from a Product Designer during a tool feedback interview)

There is also widespread awareness and concern about the environmental impacts of transporting products and materials between the UK and Chinese-based manufacturing sites.

If I'm honest, it's just really cost driven. If it's cheaper to make it out in China and when it hits our cost average we'll make it out in China… I think all the time most of the companies will pay lip service to [sustainability] or *just do it as an when. It's probably not the right thing to do, but it's just the way of the world unfortunately.*

(Comment from a Design Engineer during a tool feedback interview)

Process-related drivers and barriers for eco-innovation within Aquaplus

Tight lead times for projects meant that many engineers cited lack of time as one of the main barriers to employing eco-innovation tools. One employer suggested that, for this reason, eco-innovation tools should not be applied within projects. Instead, they should be used as part of 'Advanced Development' projects.

We should kick start that advanced development function, and part of that advanced development function should be to be looking at water-saving. It should be looking at packaging; it should be looking at not only the new product development, but also processes and production, i.e. a team focussed on how much of an impact are we having on the world.

(Comment from an Engineer during an interview)

Another issue raised by some of the design team members was that there were no environmental performance requirements within the product requirements specification. This had two impacts on the design team. First, it gave the impression that the company did not believe that the environmental performance of the product was a significant issue:

But I do think that it's not particularly obvious within the structure of our entire process, whether we care about eco issues.

(Comment from an Industrial Designer during a tool feedback interview)

Secondly, it made it difficult to justify time spent using eco-innovation tools:

If there was some sort of eco measure in place for us, for every project you need to run an assessment. This could easily be put into your NPD process for example, although we'd have to score it…So yes, if we had something like that then I definitely think it would drive us to use it each day or on a regular basis.

(Comment from an Engineer during a tool feedback interview)

However, one driving force related to the use of tools was that Aquaplus had a culture of developing their own tools and rolling them out in a systematic manner. As well as using sophisticated, third-party software such as FEA and CFD packages, the company had also built up a large collection of spreadsheet-based tools for specific calculations such as seal-squeeze force.

What generally happens is, someone will create one of those spreadsheets. They'll be used several times, changed, altered, and then they'll become common practice.

(Comment from a Senior Engineer during an interview)

As part of this tool roll-out process, the creator of the spreadsheet is tasked with validating the outputs of the tool against empirical data. If this produces a satisfactory correlation the team's Senior Engineer will present the new spreadsheet to the other two Senior Engineers who can then check over the calculations. Once this validation process is complete, the Senior Engineers are responsible for making the tool available to their team by including it in the package of approved tools described above. This system appeared to be effective at rolling-out tools and ensuring their adoption as nearly all the designers and engineers interviewed mentioned using this type of in-house developed tool.

Having both a culture of developing their own tools and a semi-formal system in place for validating and rolling-out tools was seen as a driver for eco-innovation tools as such tools could be rolled out to the company through this system.

Context-related drivers and barriers for eco-innovation within Aquaplus

The downturn in the UK construction industry and global economy means that Aquaplus were under pressure to reduce development costs. Design team members indicated that this would have a negative impact on eco-innovation as the company would be instigating fewer projects and would be less likely to support projects in which a significant amount of R&D would be required, as would often be the case for eco-innovation.

However, the corporate owners of Aquaplus were slowly beginning to increase pressure on the company to become more environmentally sustainable. A Key Performance Indicator (KPI) on environmental sustainability that assessed the percentage of product sales from 'green' products was due to be introduced. This was first noted in the benchmarking activities within the supply-chain pressures activity but was also mentioned by some of the design team who were aware of it. It was later confirmed by the research coordinator that this was partly why the company had agreed to participate in the current research as they had several 'green' product projects in their innovation pipeline that had repeatedly 'stalled'. They therefore felt that participating in the research would provide the impetus and tools to begin these projects in earnest, and so move them towards the targets for green product sales.

Legislation was also claimed to be an important driver for improving the environmental performance of Aquaplus's products:

Legislation is driving [environmentally conscious design]. The Code for Sustainable Homes first of all, the EuP; we've had RoHS; you've got the WEEE Directive…Our driver, really, is to be ahead with these compared to our competitors.

(Comment by the Environmental Manager in an interview)

However, this pressure was not being felt by the design team to the same extent who stated that they were not aware of any legislative drivers for improved environmental performance at the time. This discrepancy is discussed further in the following section.

Tools-related drivers and barriers for eco-innovation within Aquaplus

As mentioned previously, Aquaplus Engineers use a wide range of tools including in-house developed spreadsheets for specific calculations, a form of FMEA, and third-party software tools including FEA, CFD, Design for Assembly and mould flow analysis packages. It was also suggested that management were supportive of tool usage and were always open to investing in new tools:

We can use whatever tools we feel are suitable for the job, as long as we can, justify the cost and the time. So if it is a case of, we want to use some new software, we have to be able to justify the cost, i.e. the licence fee and the training and that sort of thing.

(Comment form a Senior Engineer during an interview)

Furthermore, when new tools were introduced there was a range of support mechanisms including external consultants, external training courses and a network of in-house experts. Hence, it was concluded that there was a good culture of tool usage within NPD activities at Aquaplus and that this would ease the adoption of eco-innovation tools.

With regard to the eco-innovation tools themselves, a number of issues were highlighted that might help or hinder their adoption. First, the workshops participants provided lots of constructive criticism of the tools throughout the process and were generally satisfied with the customisations made to the tools between the first and second applications, as discussed in Chapter 6. This demonstrated engagement in the research and seemed to be based on a genuine interest in developing a range of useful tools for future use within the company.

There were some reservations about using the tools in the future, even after all of the customisations. Some members of the design team were not convinced that some of the tools would help to generate new ideas:

> *In terms of the actual tool I don't know how much more we've generated from just having this tool rather than just doing a brainstorm.*

(Comment from a Senior Engineer during the 6 Windows Week 2 workshop)

However, the research coordinator believed that these doubts would be dismissed if the tools could build-up a good track record:

> *You'd have to trial run them on one or two particular product projects and demonstrate that you've got some direct kind of benefit from them, and then you start to win people over. And if you start winning people over, I guess that program managers will begin to start insisting that their team members use it, and hopefully it would become part of the process.*

(Comment from the research coordinator during an interview)

	Drivers	Strength	Strength	Barriers	
People	Motivation amongst employees to improve the environmental impacts of Aquaplus's activities.	1	1	Lack of clarity and consensus as to Aquaplus's most significant environmental impacts and which issues to focus on.	People
	Presence of a 'DfE champion' within the company.	2	1	More experienced employees cautious of tackling issues that may affect product performance such as water usage and energy usage.	
			3	Perceived lack of customer interest in reducing water or energy consumption.	
			1	Lack of direct interaction between engineers/designers and end-users.	
Process	Processes in place to evaluate and disseminate new tools.	1	2	Tight lead times means that designers are not able to apply eco-innovation tools during projects.	Process
			2	Lack of environmental targets within the requirements specification.	
Context	Increasing pressure from the corporate owners] to improve environmental performance including a new KPI.	2	2	Downturn in construction industry, reducing sales and creating pressure to limit new development projects.	Context
			1	No significant influences from environmental legislation on product design.	

Tools	Good culture of tool usage within NPD activities.	1	1	NPD Engineers would like more evidence of the positive impact/effectiveness of the tools before committing to use them on a regular basis.	Tools
	Good participant engagement with the tools and generally satisfied.	1			
	Total drivers	8	14	**Total barriers**	

N.B. Strength scale: 1 – Minor impact on planned change, 5 – Major impact on planned

Table 7.5: Force-field analysis diagram for the introduction of eco-innovation tools at Aquaplus

From the force-field analysis (Table 7.5) we can see that within Aquaplus the forces against change outweigh the forces for change by 14 to 8. This suggests that the proposed change is unlikely to be successfully adopted. A number of recommendations were made to Aquaplus to encourage a more favourable Force Field. The top three recommendations were:

1. Develop employees understanding of the environmental activities of Aquaplus's products and activities by disseminating simplified LCA results for shower products and using this information to define an eco-innovation product strategy during dedicated R&D projects.
2. Strengthen the corporate owner's core competency entitled 'Focus on the end customer', and encourage greater interaction between end customers and NPD Engineers/Designers by engaging in novel, user-centered research activities for R&D-type projects.
3. Conduct further trials of the eco-innovation tools by applying them during the early phases of an Advanced Development project. Complete a thorough cost:benefit analysis at the end of such a project in order to decide if the eco-innovation tools should be applied in subsequent projects.

7.2 Cross-case analysis of drivers and barriers

In this section, cross-case analysis is used to search for more general trends and patterns. The analysis builds on the findings from each of the case studies in the previous chapter, as was shown in Figure 7.1.

7.2.1 Legislation

Legislation is often cited as a driver for eco-design activities (Argument et al., 1998, McAloone, 2000, Knight and Jenkins, 2009), and this was reaffirmed in discussions with companies during the pilot study. However, it was not evident that legislation would be as important a driver for eco-innovation. This is because environmental legislation often aims to raise the standards of the worst performing companies but might not impact the leading edge technology. For instance, the recently introduced Energy-using Products (EuP) Directive (European Commission, 2005) requires manufacturers of affected products (such as electric motors, water heaters, lighting products etc) to meet targets relating to product performance characteristics such as standby energy consumption or thermal efficiency. These targets are set based on the 'Best Available Technique Not Entailing Excessive Cost' (BATNEC). Hence, the targets set are, by their nature, able to be met using existing, commercially-viable technology.

The evidence from the case studies did suggest that environmental legislation was a driver for eco-innovation for MetroTech and Medipro. However, if we consider these examples in more detail we find that the legislation was in fact driving more conventional eco-design activities. Within MetroTech, the driver was the likelihood of the REACH and EuP Directives having some impact on the design of the company's products. The company was therefore looking to reduce the cost of complying with these Directives and to gain some competitive advantage in doing so. This was in part due to the fact that the company had taken steps to ensure that all their products were RoHS compliant, even though only a small minority of their products were affected by the Directive. However, there was disappointment amongst staff that the cost of becoming RoHS compliant did not appear to have been justified in terms of improved sales. The company was therefore keen to do better with subsequent pieces of legislation. Nonetheless, the company was only interested in gaining more advantage from compliance with the legislation, not in going beyond the requirements of the legislation. The legislation was therefore a driver for eco-design or pro-active compliance activities, neither of which counts as eco-innovation per se.

This was mirrored at Medipro who used the eco-innovation tools to consider ways of eliminating Beryllium Copper from their products. Whilst there was no legislation in place at the time, they expected this to change within the near-medium future. It was therefore another case of early compliance activities rather than eco-innovation.

It is therefore suggested that, unlike eco-design, the current raft of environmental legislation affecting the electronics industry is not a driver for companies to invest in eco-innovation activities or the introduction of eco-innovation tools.

7.2.2 Senior management support

A lack of senior management support, or more precisely, the perception from staff that senior management did not fully support eco-innovation, appeared to be a contributory factor in a number of the barriers to eco-innovation previously highlighted. A lack of senior management support has previously been reported as a barrier to ECD activities (Handifield). Whilst there was insufficient evidence to draw general conclusions about *why* senior management do not communicate their support for eco-innovation, the consequences within the case study companies were manifold.

First, it was apparent from comments by design team members that they felt that they were not responsible, or did not have the authority, to engage in eco-innovation activities without permission or authorisation from somebody else (senior management, a project manager, the eco-design facilitator) or something else (the requirements specification provided by marketing). Whilst the source of authority varied between companies and designers, the common thread was that they all appear to be symptomatic of a top-down organisational culture in which authorisation must be received down through the 'chain of command' before action can be taken. The conclusion here is that very little or, most likely, no eco-innovation activity will take place within a company that does not have explicit support from the senior management team. This finding is supported to some extent by the work of van Hemel (2002) who found that eco-design performance within Dutch SMEs was not improved by the support of the CEO but that the decision of the company to engage in eco-design in the first place was likely to have been influenced by the CEO.

Secondly, it was noted within MetroTech that although the senior management had not given explicit support for eco-innovation activities, they had been informed of the company's participation in the current research and had not objected. This was viewed by one Engineering Manager as being a tacit form of support from the Senior Management team. Unfortunately, none of the design team members made the same subtle distinction between being against the introduction of eco-innovation and not explicitly supporting eco-innovation. The design team members therefore assumed that the Senior Management team did not support eco-innovation.

In summary, a lack of explicit support for eco-innovation from the Senior Management was viewed by design team members as a sign that the Senior Management team were not in favour of eco-innovation. In such cases, design team members appeared less enthusiastic to engage in eco-innovation activities. It is therefore concluded that Senior Management support must be clear and explicit if a company is to begin eco-innovation activities.

7.2.3 Separating out radical innovation from NPD activities

Within Medipro, Intelliprod and Aquaplus there were barriers associated with using eco-innovation tools within NPD projects. Primarily this was related to lack of time and/or manpower. Designers from across these companies stated that conventional NPD projects would often be prioritised over more long-term, radical innovation projects due to tight lead times. Within Intelliprod it was noted that this became a vicious circle, or a ‘merry-go-round’ as their Director of Innovation put it, because without any radical innovations in the pipeline the company had to do more incremental design projects to try and keep retailers happy; and by doing more incremental design projects they had less resource available to initiate some radical innovation projects.

Another barrier to conducting eco-innovation activities within an NPD project noted within Medipro was that the level of technical risk associated with eco-innovation was likely to be too high to be managed within an NPD project.

For these reasons it was recognized that there was a need to separate eco-innovation activities from NPD activities. The idea of keeping eco-innovation activities separate from NPD activities goes against much of the advice within the ECD literature, which suggests that integration of ECD within NPD activities is a key success factor (Ritzén, 2000, Lindahl, 2005, McAloone, 2000). Jones (2002) had previously suggested running eco-innovation workshops as a distinct phase of activity, prior to the launch of an NPD project. However, this recommendation was not based on any empirical evidence. The evidence from this research points to a conflict between eco-innovation and NPD activities. Furthermore, when Medipro generated some promising ideas during one of the eco-innovation workshops, their next planned step was to launch an ‘advanced concept development’ project to further investigate these ideas. The research coordinator at Medipro explained that this type of project was run ‘off-line’ of the NPD process and had successfully been used in the past to develop new technologies that were later integrated into an NPD project. From this evidence it is concluded that maintaining separation between day-to-day NPD activities and eco-innovation activities is important for the success of eco-innovation. This conclusion is in keeping with innovation management literature which has previously suggested that radical innovation activities should be separated from incremental innovation activities, either through distinct management structures (O'Reilly and Tushman, 2004), an ‘innovation hub’ (O'Hare et al., 2008) or even a physically separate organisations, such as Lockheed Martin’s famous ‘Skunk Works’ (Rich and Janos, 1994).

7.2.4 Lack of eco-innovation strategy

Apart from Medipro, none of the participating companies had any form of strategy or procedure in place for eco-design or eco-innovation. It is believed that this fact was at least in part responsible for some of the key barrier to eco-innovation highlighted in the case study companies. Without a clearly defined and articulated strategy in place for eco-innovation it is understandable that staff engaged in eco-innovation activities are confused and even sceptical about what they are trying to achieve. Some of the barriers to eco-innovation previously and associated with the lack of an eco-innovation strategy are:

- Concern that environmental performance will be pursued at the cost of more general innovation (Intelliprod).
- Debate and confusion over the selection of particular eco-innovation issues to target due to a lack of evidence to justify these choices (Medipro, Intelliprod and Aquaplus).
- Feeling from staff that the company’s day-to-day operations should become ‘greener’ before trying to sell ‘green’ products (Intelliprod).
- Lack of environmental targets within the requirements specification (MetroTech, Intelliprod and Aquaplus).
- Lack of long-term targets for company or product environmental performance (Intelliprod).

The research points towards the creation of eco-innovation strategies as a way for companies to overcome some of these barriers (and do so in a more holistic manner). For this reason it is strongly recommended that companies invest time and effort in developing an eco-innovation strategy prior to attempting to introduce eco-innovation tools.

But what type of eco-innovation strategies exist and how should companies chose between them? These types of questions have received relatively little attention within the academic literature and it is only recently that more analytical approaches to help companies with these decisions have been developed. Orsato (2006) has defined four types of environmental strategy that a company can adopt based on how it achieves a competitive advantage, and the competitive focus it selects. The two forms of competitive advantage are lower costs, simply offering the same product at a lower price than competitors; or differentiation, offering unique functions, features or qualities that a customer values. The competitive focus can either be on organisational processes or on the products or services that the company offers to the world. The leads to the following four possible environmental strategies that a company can adopt:

1. Eco-efficiency – reduced cost of sales is achieved by eliminating waste in manufacturing or improvements in efficiency within the supply chain. The popularity and widespread uptake of both quality-management systems such as ‘Lean Manufacturing’, ‘Six Sigma’, and environmental management systems such as ISO 14001, means that this is strategy is the default within many manufacturing companies.

2. Beyond compliance leadership – when the RoHS Directive was announced, the first component suppliers to offer RoHS-compliant components to manufacturers held a competitive advantage briefly whilst the rest of the industry caught-up. Now that RoHS compliance has become the default, this feature no longer provides a competitive advantage and hence component suppliers must find new ways to develop a competitive advantage. This might be achieved by signing-up to voluntary schemes that set standards for environmental performance or reporting, beyond that required for legal compliance.

3 .Eco-branding – gaining a premium price for products based on their environmental credentials. According to Reinhardt (1999), this type of strategy can only work if the following three conditions are met: the customer must be willing to pay the costs of ecological differentiation; reliable information about the product's environmental performance must be available to the consumer; and the differentiation should be difficult to imitate by competitors.

4. Environmental cost leadership – this strategy relies on eco-design or eco-innovation to reduce product costs for price-sensitive markets. Whilst the resultant products generally have significant environmental benefits compared to competitor products, the products are not marketed on this basis as customers are not willing to pay a premium for these characteristics.

Companies can therefore use this framework to select an appropriate environmental strategy by identifying which of the four outlined above is most closely aligned with their overall business strategy. Because eco-innovation is a product-focused activity, it is most appropriate for the ‘eco-branding’ and ‘environmental cost leadership’ strategies. Companies that chose to pursue the process-focused ‘eco-efficiency’ and ‘beyond compliance leadership' environmental strategies would derive less value from eco-innovation and might therefore decide not to introduce eco-innovation tools.

The Orsato framework can help companies to decide on their environmental, and hence eco-innovation strategy, but are a number of further issues concerning the eco-innovation strategy must be addressed. These include: who should be involved in formulating an eco-innovation strategy; what needs to be detailed within the strategy; and how should those responsible go about creating this strategy?

Tackling these questions one at a time, who should be involved is not clear. If we turn to the literature on organisational change management, we find that there are opposing views on whether significant strategic changes (such as the introduction of eco-innovation tools and activities) should be implemented in a 'top-down' process led by the CEO and management, or as a 'bottom-up' activity which encourages much wider participation in the dialogue. Summarising this dichotomy, typified by the works of Warren Bennis and Jay Conger, Dunphry writes:

> *For Bennis knowledge and wisdom about change reside primarily in the organisational members below the senior level, and leaders are a potential source of disaster. To tap organisational resources and overcome their own limitations, leaders need to ensure that organisation members participate actively in all aspects of the change process. For Conger knowledge and wisdom about change reside in the CEO and the top team, while other employees are a potential source of error, inadequacy, and special interest pleading. To ensure that strategic change, generated in the top team, is not subverted, it is vital that other organisational members faithfully carry out the initiatives generated from the top of the organisation. (Dunphy, 2000 pp.126)*

Dunphry goes onto to suggest that this paradox can be resolved by taking a middle-ground approach in which the strategic overview of the top team is informed by the in-depth insights that can be offered by the skilled professionals who make up the organisation. Of course, fostering an environment in which 'the leaders' and 'the led' can work together effectively to create a shared vision is a considerable challenge in itself and is beyond the scope of this work.

Regarding the second question of what needs to be included in an eco-innovation strategy, based on the problems highlighted previously, it is suggested that the following points should be addressed:

- *The rationale and business case for engaging in eco-innovation activity* – this will ensure that staff are clear as to the expected business benefits from pursuing eco-innovation.
- *Guidance on how to select the environmental aspects of the company's activities to target within eco-innovation projects* – this may be a fixed set of focal areas, as was the case within Medipro, or a systematic method which can be applied at the beginning of each project. In either case, the environmental aspect selected must be justifiable in terms of the potential environmental and business benefits.
- *Long-term targets for operational environmental (associated with production) and eco-innovation (associated with products) performance* – such targets will help to demonstrate a long-term commitment on the part of the company and will set the expectation levels across the company.
- *A plan for how eco-innovation activities relate to the company's conventional NPD and innovation activities* - details of the type of projects that will be targeted for eco-innovation activities (presuming that only a small proportion of projects will contain an eco-innovation element). This topic is discussed further in the following section.

In summary, the lack of an eco-innovation strategy is believed to be a significant factor in a number of the barriers to eco-innovation highlighted within the case study companies. It is therefore suggested that companies create an eco-innovation strategy document, addressing the points listed above. The eco-innovation strategy issue is discussed further in the following section which presents a model of the eco-innovation process.

7.3 A model of the eco-innovation process

The overall aim of this chapter has been to establish what companies can do to introduce eco-innovation activities and tools with minimal cost and effort whilst maximising the long-term success and benefit. In the previous sections, the drivers and barriers for implementing eco-innovation have been highlighted and analysed at both the case and inter-case levels. One issue for companies planning to introduce eco-innovation tools that has not yet been addressed is 'How do eco-innovation activities relate to existing strategy, innovation and NPD activities?'. This section attempts to answer that question by proposing a model of eco-innovation based on the findings from the previous sections, evidence from the benchmarking activities and relevant literature.

First, it is worth considering why a model of eco-innovation activities is required and what benefits it will bring. The requirement stems from the fact that very few companies in the world have ever engaged in eco-innovation activities. A much larger number of companies have conducted some kind of eco-design activities and some of these, such as Medipro, have a procedure in place that will help to understand how eco-design relates to existing strategy, innovation and NPD activities. But eco-innovation is different from eco-design and it has previously been noted that some of the findings concerning the adoption of eco-innovation tools are not the same as those for eco-design, and are even contradictory in some areas. Therefore, there is a need for a model of eco-innovation, distinct from previous models of ECD activities (e.g. Ritzén 2000; McAloone 2000).

The benefits to a company planning to introduce eco-innovation activities of having a model of eco-innovation are:

- It can be used to inform discussions with internal stakeholders when making the case for, and planning the introduction of, eco-innovation activities.
- It can be used to identify potential managerial issues sooner and the key interfaces that will require special attention and resource.

The disbenefit of describing a model of eco-innovation is that it is a static model that idealises the system of consideration and risks deceiving the reader into under-estimating the challenge involved in implementing eco-innovation by presenting an over-simplified view. It is therefore recommended that companies should spend some time considering how the model, outlined below, could be adapted and applied within their own context.

The model was based on the findings from sections 7.1 and 7.2 and is an attempt to overcome some of the barriers to eco-innovation activities therein. The key features of the model are shown in Figure 7.3.

Eco-innovation strategy (Section 7.2.4) - the eco-innovation strategy details why the company had decided to engage in eco-innovation, who is responsible for managing eco-innovation, guidance on how to select issues to focus on etc. Here it is stressed that the eco-innovation strategy is informed by a wide range of factors including business strategy, competitor activity, customer expectations etc. The strategy should receive input from Environmental, Health & Safety staff as they will be heavily involved in the achievement of company goals. Input should also be received from the design team as it is they who will have to meet the product-related eco-goals and they may be able to provide useful insight into the areas of the product that have the greatest potential for significant innovation.

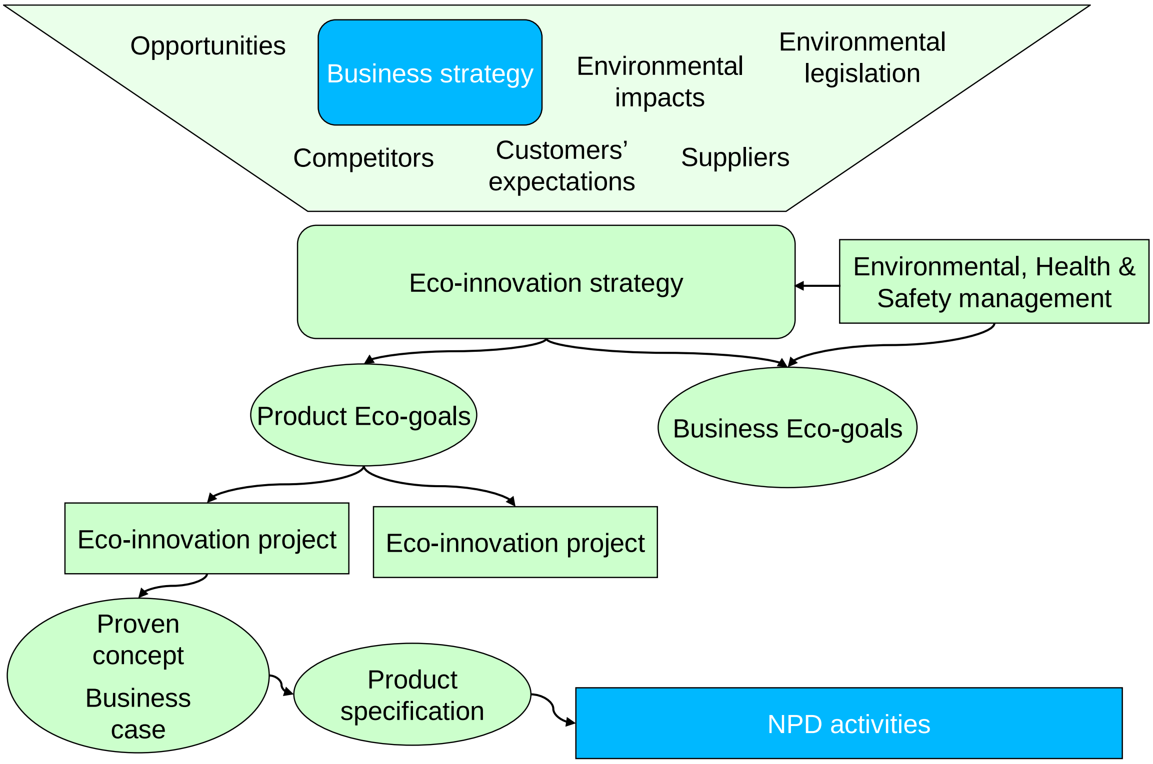

Figure 7.3: The initial model of eco-innovation activities

Product and business eco-goals – one of the key outputs from the eco-innovation strategy should be the creation of environmental targets, or 'eco-goals' at both the product and business-level. For the products, this could be a target such as: 'decrease product in-use energy consumption per hour of usage by 30% within 4 years'. For the company, the target should be formulated in coordination with Environmental, Health & Safety staff and could be: 'decrease operational energy use per euro of sales by 40% within 5 years'. Both types of goal should be set over a medium-to-long time frame and must be sufficiently ambitious that they could not be achieved with 'business as usual' activities. In doing so, this will generate the need for eco-innovation projects, inspire design teams to come up with more radical solutions and demonstrate the company's long-term commitment to eco-innovation.

Separate eco-innovation projects (Section 7.2.3) – to ensure that eco-innovation activities can be pursued away from the pressures and time constraints of NPD activities, it is suggested that they are completed in a dedicated form of 'pre-development' or 'research' project. Companies might even consider running such projects within an 'innovation hub' if such an organisational structure exists. By conducting one or two of these dedicated eco-innovation projects per year (rather than trying to incorporate eco-innovation into every project): the risk of staff being sidetracked by more urgent NPD projects should be reduced; the quality of the projects and the outcomes should be better; and any staff fears that eco-innovation is being pursued at the expense of ‘normal innovation’ should be reduced.

Proven concept, business case and product specification as project outcomes – if eco-innovation projects can deliver a proof of concept prototype or simulation as a technical outcome then it should then be feasible to incorporate the new technology or concept into a commercial product. Of course, technical feasibility is only half of the story. A successful product needs a market which is of sufficient size and value to be of interest to the company, and the product itself needs to perform to an acceptable standard. The eco-innovation project team, and in particular marketing staff, therefore need to devise a business case in support of the future product and, together with the design team, formulate a detailed requirements specification. With these three elements in place, a decision can be made by the management team whether or not to launch a full NPD project for the eco-innovation concept.

Project execution within a ‘normal’ NPD project – with the major technical and commercial risks resolved, or at least sufficiently understood, the development of the eco-innovation can be executed with a normal NPD project. This reintegration of the project should help to reduce any organisational resistance to the eco-innovation, which may be particular problem if the previous stage has been conducted within the setting of an innovation hub. This will also allow the project to tap-in to the resources of the mainstream organisation whilst avoiding the need and cost of separate management systems for eco-innovations.

In summary, the eco-innovation strategy creates the business context for eco-innovation and provides the framework for setting business and product-level eco-goals which in turn drive the need for eco-innovation projects. A small number of dedicated eco-innovation projects are conducted each year, removed from the pressures of NPD activities, which generate a proven concept, a supporting business case, and a detailed requirements specification as outputs. Once approved, these are fed into NPD projects which are controlled using the company’s existing management processes and systems.

This model was presented to company representatives at the round-up seminar. The seminar was attended by management representatives from MetroTech, Intelliprod, Medipro, Aquaplus, Environ and Company III from the preliminary study. An audio recording of the discussion was taken and later reviewed but not transcribed or coded.

When asked about the usefulness of the model presented the participants’ responses confirmed that the model seemed logical and was a good approach to the challenge of managing eco-innovation activities. The discussion therefore quickly turned to the issue of how, as eco-innovation practitioners, the participants could gain sufficient support across their respective businesses to implement the model. This discussion delivered the following conclusions, which have been integrated into the final model for eco-innovation management shown in Figure 7.4.

- *Communication and reinforcement* – it was suggested that one of the key difficulties of this type of model was communicating it and gaining 'buy-in' across the business. The participants felt that 'academic' models were of little interest to managers and that to gain support initiatives need to be pitched in terms of their benefits to the business. One possible solution proposed by the participants was to reinforce the model by also communicating success stories from previous eco-innovation projects that had made it to market. Obviously, if these examples need to come from within the company, this type of positive reinforcement can only occur once at least one successful eco-innovation project has been completed.
- *Building the business* case – Continuing from the last point, it was suggested that to help build the business case it might be necessary to begin with some small scale projects by simply applying the eco-innovation tools with NPD projects. In doing so, the outcomes of these small projects could be used to gain support amongst the design team and the wider organisation and help generate a stronger business case to present to Senior Management. This was described as a 'bottom-up' approach to building the 'impetus for eco-innovation'. An alternative approach to building the business case proposed was to conduct a life cycle assessment of a product and use the results to suggest projects that would begin to tackle the major life cycle impacts of the product whilst also delivering other business benefits. This type of strategy might be most effective for products whose major environmental impacts are things such as energy use in manufacturing where improvements will lead to direct cost savings for the business.
- *Business eco-goals come from business strategy* – Finally, it was felt that the 'business eco-goals' should be part of the core business strategy and not only an output or consequence of the eco-innovation strategy. This idea was supported by the Medipro representatives who suggested that this was similar to their existing approach in which environmental objectives are an integrated part of the corporate strategy.

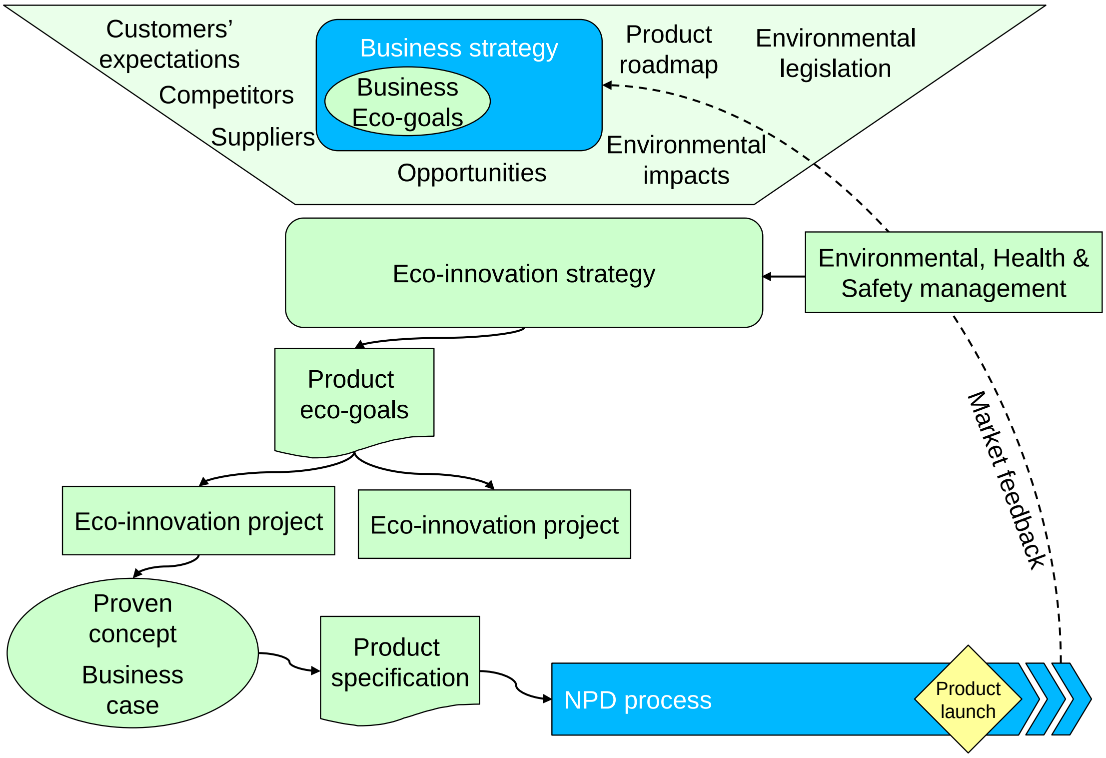

Figure 7.4: The revised model of eco-innovation activities

In conclusion, this section has tackled the question 'How do eco-innovation activities relate to existing strategy, innovation and NPD activities?' and has presented a model of eco-innovation activities that could help companies with internal communication and in planning the introduction of eco-innovation tools. The model has been reviewed by representatives from the case study companies who felt it was a good approach based on their existing knowledge of eco-innovation, but they were concerned about how they would gain sufficient support for eco-innovation to get such a model implemented within their organisations. This led to recommendations with respect to communicating the model, building the business case for eco-innovation and the role of business eco-goals.

7.4 Conclusions

This chapter has attempted to understand what companies can do to introduce eco-innovation activities and tools with minimal cost and effort whilst maximising the long-term success and benefit. Section 7.1 provided an in-depth, case-by-case review of the drivers and barriers for the long-term adoption of eco-innovation tools within each of the four companies that participated in the tool introduction studies. This analysis, drawing directly on interview data and other supplementary sources, was structured by the use of Force-Field Analysis diagrams and the grouping of drivers and barriers under the themes of 'People', 'Processes', 'Context, and 'Tools'.

Section 7.2 was based on a higher level, cross-case analysis to identify significant themes across the four case studies. It was found that the current raft of legislation affecting the electronics industry does not provide an incentive for investment in eco-innovation activities as the environmental performance targets can be met with commercially available technology; that senior management support must be clearly and explicitly communicated to staff if they are to begin to engage with eco-innovation; that eco-innovation projects were likely to suffer if the staff involved in them were not separated to some extent from the day-to-day pressures of regular NPD activities and that the lack of an eco-innovation strategy was the likely root cause of a number of significant barriers. Recommendations were made covering: how to decide on an environmental and eco-innovation strategy; who should be involved in deciding this strategy; and what an eco-innovation strategy document should contain.

Finally, within Section 7.3 a model of how eco-innovation activities relate to existing strategy, innovation and NPD activities was proposed. This model is fundamentally different from those for eco-design as it was found to be necessary to separate eco-innovation activities from the day-to-day NPD and incremental innovation activities. The suggested industrial uses of this model are:

- It can be used to inform discussions with internal stakeholders when making the case for, and planning the introduction of, introducing eco-innovation activities.
- It can be used to identify potential managerial issues sooner and the key interfaces that will require special attention and resource.

Finally, recommendations were made on how to communicate the model of eco-innovation, building the business case for eco-innovation and role of business eco-goals.

8 Conclusions

This chapter begins by providing a summary of the research. The research problem is reiterated and it is shown how the research objectives have been met. The limitations of the study are noted in Section 8.2 before presenting a review of the research findings in Section 8.3. The findings are presented in this section in relation to the research question that they help to answer. In Section 8.4 the main contributions to knowledge are highlighted, and in Section 8.5 the recommendations for future research are presented.

8.1 Research summary

This research was initiated following discussions with Environ UK Ltd. who, based on some 10 years experience of working with clients to implement ECD practices, felt that there was a need for innovation tools that could help to progress companies from incremental approaches to reducing the environmental impacts of their products, such as DfE and 'eco-design', towards a more radical, eco-innovation approach. The research focused on the development and introduction of tools to support the eco-innovative process and aimed to establish what impact tool customisation - based on an understanding of the requirements of the company and the design team - has on the tool introduction activities and the likelihood that the tools will be adopted into the long-term practices of the company. The organisational drivers and barriers for the long-term adoption of eco-innovation tools were also investigated. The ultimate aim being to increase the number of eco-innovative products making it to market.

Chapter 1 highlighted that there is both an environmental imperative to improve the environmental performance of products, and an increasingly compelling business case centered around: opportunities for innovation; legislative compliance; and Corporate Social Responsibility requirements. It went on to note that despite these drivers, the types of ECD approach companies take are often incremental in nature, leading to small improvements in environmental performance (Pujari, 2006) rather than the type of step-change reduction in environmental impact that might be delivered by more radical approaches such as eco-innovation. It was argued that one of the likely causes of this was related to eco-innovation tools, specifically, that the limited number and range of tools available was impeding the development of eco-innovation. It was also noted that experience from DfE and eco-design has shown that even when a good range of support tools do exist, they still struggle to gain adoption within industrial practice (Baumann et al., 2002, McAloone et al., 2002). This research attempted to address both of these challenges: developing design and innovation tools that are appropriate for eco-innovation; and ensuring that such tools are adopted into industrial practice. The research aim was therefore formally stated as follows:

> *Research is required to understand how new innovation support tools can be developed and implemented within companies such that they are adopted into the working practices of the organisation and contribute to the development of eco-innovative products.*

From this research problem a number of research objectives were set. Table 8.1 provides a summary of how these objectives have been achieved.

Objective	How was it achieved?
RO1. - To identify the following from the academic literature: • The main activities in the development of eco-innovative products. • The types of ECD tools currently available. • The challenges associated with implementing ECD tools.	Ten eco-innovation tools were developed by adapting existing, mainstream innovation tools of which five were selected for industrial testing.
RO2. - To develop a suitable research methodology and define pertinent research questions.	A research methodology based on action research and the case study approach was developed along with a number of research questions.
RO3. - To develop and trial a range of benchmarking activities to help understand a company's requirements for eco-innovation tools.	Innovation and environmental benchmarking activities were developed and trialled during the preliminary industrial study.
RO4 - To gain a better understanding of companies' current responses to drivers for ECD through a preliminary industrial study.	The benchmarking activities were applied at six companies leading to a better understanding of how companies are responding to drivers for ECD and how they manage NPD and innovation activities.
RO5 - To identify a number of existing design and innovation tools from the academic literature that have the potential to be adapted for application in an eco-innovation context.	Ten design and innovation tools were identified from the academic literature. One tool, 'empathic design' was deemed unfeasible to test within the research and was rejected.
RO6 - To adapt said tools for application in an eco-innovation context.	The nine remaining tools were adapted for eco-innovation by incorporating environmental considerations in a variety of ways.
RO7 - To assess the suitability of the eco-innovation tools through in-house trials.	In-house tool testing workshops were completed. Participant feedback, observations and the tool outputs were used to evaluate the tools leading to the selection of five tools which were taken forward for industrial trials.

RO8 – To gain a better understanding of companies' needs with respect to eco-innovation tools.	The previously developed ECD, MPD and innovation benchmarking activities were completed with six EEE producers to help build a better understanding of the companies' needs.
RO9 - To introduce these eco-innovation tools to a number of companies who design and produce electrical or electronic equipment through a series of one-day workshops.	Five eco-innovation tools were introduced to a total of six companies through a series of one-day workshops.
RO10 – To establish the eco-innovation tool requirements of the design team through a series of tool introduction workshops and feedback interviews.	Two-week tool introduction studies were completed with four companies during which selected eco-innovation tools were introduced to the design team and individual interviews conducted with design team members to gain feedback on the tools and their general tool requirements .
RO11 - To customise the eco-innovation tools based on an understanding of the requirements of a company and its design team.	Based on the tool feedback, the design team requirements and the company benchmarking data the eco-innovation tools were customised to the needs of each company.
RO12 - To evaluate the success of the tool customisations and the likelihood of eco-innovation tools being adopted into the long-term practices of a company.	The customised tools were applied to real problem and opportunities as defined by the companies. Group feedback and individual interviews were used to evaluate the success of the tool customisations.
RO13 - To investigate the drivers and barriers to the adoption of eco-innovation tools.	Within the four case-study companies, interviews were conducted with members of the design team and senior management on the topic of drivers and barriers for eco-innovation. Qualitative analysis of these data led to a range of findings in this area which in turn can be used to encourage long-term adoption of eco-innovation tools.

Table 8.1: Summary of the research objectives and how they were achieved

Within Chapter 3 a research methodology was formulated to guide the intervention-based, industrially-located type of research activities that were essential for the topic of study. The methodology was founded on a realist perspective and influenced by both Action Research and Case Study approaches. The qualitative data was analysed using the approach described by Eisenhardt (2002) and used a bespoke coding scheme which was validated through an intra-coder reliability assessment.

Within this framework five research questions were formulated and a series of research activities developed to provide the evidence with which to answer those questions. Prior to commencing the industrial research activities, a tool introduction process was defined based on the previous work of Ritzén and Lindahl (2001). The main research activities are listed in Figure 8.1, which also shows the relationships between the research questions, the research activities, and the stages of the tool introduction process. In Section 8.3 the findings from each of these questions are discussed although before this, the limitations of the findings are noted in the following section.

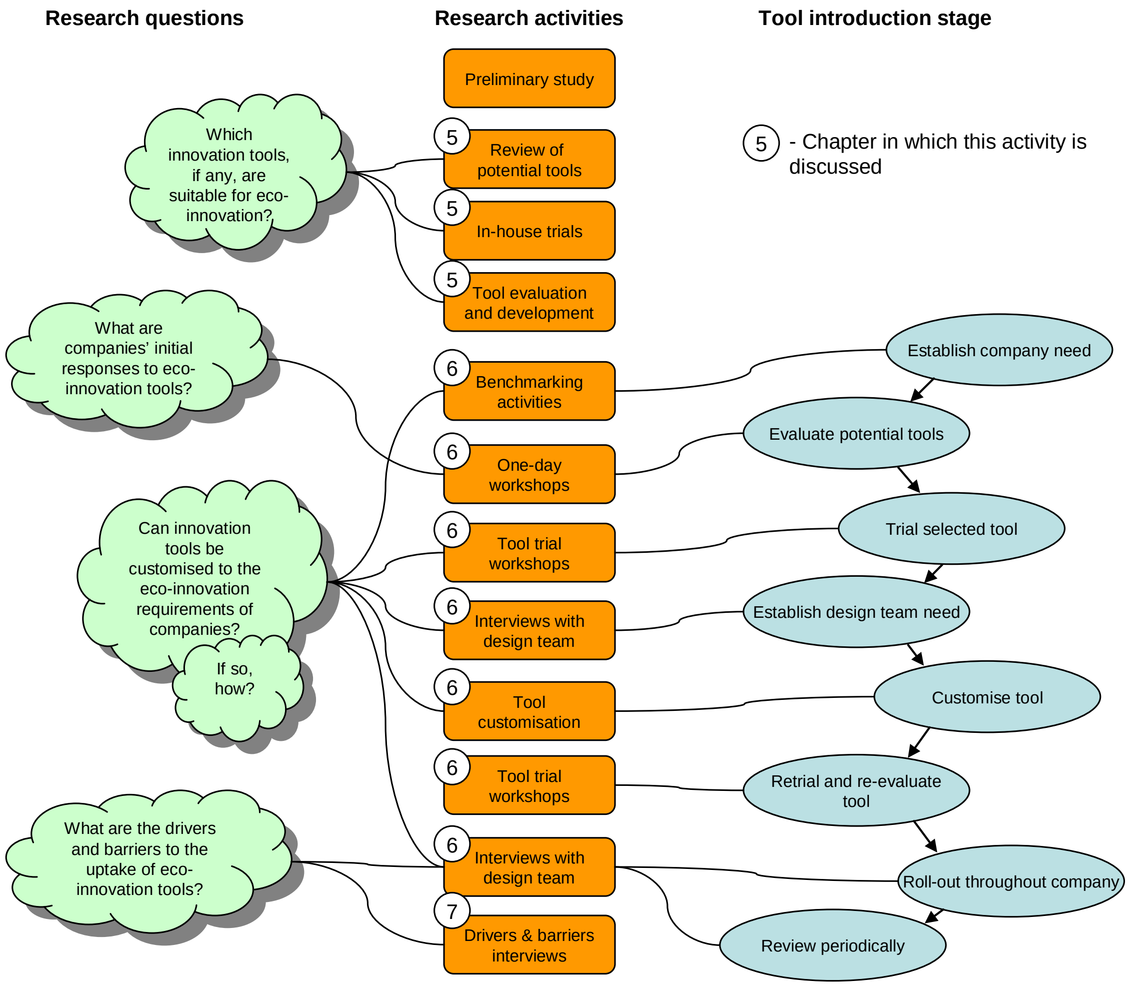

Figure 8.1: Relating the research activities to the research questions and the tool introduction process

8.2 Limitations of findings

Before discussing the findings it is important to note some of the limitations of the study. The primary limitation was that, although the evidence collected was able to verify the success of the tool introduction activities, it was not possible to confirm that a successful tool introduction will guarantee that a tool will be adopted in the long term.

The findings from this study are also limited in terms of their generalisability due to the nature of the case study companies. The case-study companies were a 'self-selected sample' in that the research was advertised to many companies who met certain basic requirements but these were amongst a relatively small number of companies that responded to advertisements. These companies therefore already had some interest in eco-innovation and hence the findings may have been different if a systematic sampling strategy had been used. The sample also comprised only European-based, EEE producers. It is therefore expected that the findings can be generalised to other Europe-based EEE producers that have an interest in eco-innovation but it is not clear if the findings will remain valid for companies that do not fit into this category.

At several points within this thesis it has been noted that eco-innovation has a number of peculiarities in terms of its focus, timing and tool requirements. This means that some of the specific requirements relating to eco-innovation tools may not be applicable to other types of design or innovation tool. However, it is felt that the tool introduction process should be applicable to any type of design or innovation tool within a European-based EEE producer.

Finally, this study was focused on eco-innovation. However, in some cases, the activities being described as eco-innovation were in fact closer to a more conventional eco-design approach. Efforts were made to search for the possible effects of this and where an effect has been observed, this has been highlighted within the findings. This could be avoided in future studies of eco-innovation by including more rigorous case selection filters.

8.3 Reflections on the research methodology

As with any research project, learning occurs both with respect to the research subject matter and with respect to the research methodology. This section attempts to articulate some of the learning concerning the research methodology by providing reflections on some of the key issues.

Selection of the innovation tools – The initial search of the academic literature for innovation tools that were potentially relevant for eco-innovation was effective in that nine tools were identified from this. However, it is important to note that it was not the intention of this search to identify all the tools that were relevant for eco-innovation. There are potentially many more existing innovation tools that can be adapted for the purposes of eco-innovation that have not been discussed within this research. In particular it is considered an oversight that the literature on systems engineering was not reviewed for potential tools, particularly given the focus on defining problems at higher systems levels. Whilst the 'Functional Analysis' and Objectives Tree Diagram' tools draw on some principles of systems engineering, it seems likely that there are many more sophisticated tools and approaches within the systems engineering domain that could be relevant for eco-innovation.

Another aspect of the tool selection that could have been improved was the selection of the final five tools for the toolbox for eco-innovation. The process used to make these decisions was based predominantly on: the views of the in-house trial participants; and the researcher's own assessment of the quality of the ideas produced and the merits of the tools. An alternative approach would have been to have worked with industrial collaborators in this phase by conducting a similar range of workshops and then allowing the design team to select the tools to take forward. Whilst this process would still have been subjective, by working with the target audience (rather than a group of academics, who in this case had limited design experience) the probability of identifying the most effective and valuable tools would have been greatly increased.

Use of design experiments - When selecting the research methodology, it was suggested that design experiments were not appropriate for the research as they would not have helped to investigate some of the contextual, organisational issues surrounding tool introduction and adoption. However, in Section 6.6.3 it was noted that during one of the Medipro Week 2 workshops, a short 'control' session was conducted at the request of the participants in order to compare the ideas generated with and without the use of the eco-innovation tool. Although this comparison had significant methodological flaws, it did help to convince the design team that the eco-innovation tool brought some benefit by helping to generate some solutions that had previously not been considered.

This leads to the question, 'could the use of design experiments have added value to the overall case study/action research approach?' On reflection, the research might well have benefited from the use of design experiments, particularly to compare the effectiveness[7] of using eco-innovation tools to not using eco-innovation tools. This would have provided the design team with some objective evidence of the benefit, or otherwise, of using the tools. Furthermore, if the experiment analysis could have been conducted within the space of days rather than months, the feedback might have had an important (positive) impact on the design team's view of the eco-innovation tools at the time when they were being introduced.

Parallel cases – All of the four main case studies completed a very similar research process, with each company presented with exactly the same eco-innovation tools initially. This approach was chosen to facilitate cross-case analysis. However, an alternative approach would have been to complete three of the case studies in this parallel manner,

[7] Consideration would have to be given as to what metrics of 'effectiveness' were used in the analysis of such experiments e.g. total number of ideas, time taken to generate ten ideas etc.

made changes to the eco-innovation tools and the research process based on the learning from these cases, and then gone on to conduct the fourth case study. Completed in this more iterative manner, the fourth case study would have provided an opportunity to validate the findings and conclusions from the first three cases concerning the customisation of the tools and the best way to introduce the tools. This would have been in keeping with the action research process, which emphasises the benefits of multiple learning cycles in iterating towards a more effective solution.

Confidentiality – The identity of the case-study companies, the real projects tackled within the Week 2 workshops and the outputs from those workshops could not be discussed within this dissertation for confidentiality reasons. Confidentiality has both benefits and disbenefits from a research perspective. The main benefit was the freedom to honestly and critically analyse the design and innovation activities and culture of the case-studies. This freedom may have come under threat from a pressure to censor the more negative comments had the anonymity for the companies not been maintained. The primary disbenefit was not being able to discuss the Week 2 workshop tasks or outputs. Had these been presented the reader would have benefited from a better understanding of the use of the tools within the companies and their effectiveness at generating novel, eco-innovative concepts.

Tool feedback method – For the in-house trials, one-day workshops and the Week 2 workshops of the tool introduction studies, a group feedback form was completed for each of the tools tested. The aim of collecting feedback in this way was to promote discussion which could be captured on the audio recording and subsequently analysed. This approach was beneficial in that on a number of occasions interesting and insightful comments were captured on the audio transcribe that were not included on the feedback form. However, there were a number of issues with this method.

First, the responses obtained were likely to represent the 'middle-ground' of the individuals present, eliminating any extreme views. This goes against validity-increasing approaches such as theoretical sampling and searching for disconfirmatory evidence, which would suggest that sources of more extreme views should be sampled for their potential to prove, disprove or extend emergent conclusions or theories.

Secondly, this method did not take into consideration the psycho-social factors that may have influenced the responses obtained e.g. did the views of one dominant personality overly influence the group? Did the group ignore dissenting voices? Etc.

These issues were overcome to some extent during the Week 2 activities by conducting further individual interviews. However, a better approach might have been to ask for individual feedback forms to be completed before then starting a short group discussion. This would have helped to ensure that the views of all design team members were obtained whilst also providing the opportunity for more informal discussion.

Coding of the qualitative data – The process of coding the qualitative audio data sources was found to be very useful as, once complete, it allowed the researcher to very quickly review the quality and quantity of evidence supporting a finding, thereby allowing the researcher to have greater confidence in the final set of findings presented. Furthermore, it is hoped that the extensive use of quotes in Chapter 7 makes the link between the source data and the findings more transparent and therefore more convincing for the reader. This again was facilitated by the use of the coding scheme and the qualitative data analysis software.

One aspect that could have been improved was the selection of the sources to code and analyse. Whilst efforts were taken to select sources that might disprove some of the initial findings it is possible that the wrong sources were selected for this purpose, or that other themes were missed due to the focus on sources that either proved or disproved the initial findings. The obvious way to overcome this would have been to transcribe and analyse all of the audio sources, but this was not possible due to time and resource constraints. As an alternative, if the individual feedback forms had been used in the one-day workshops as suggested above, it may have been possible to use these feedback comments to help identify individuals that were more sceptical or critical of the eco-innovation tools. This approach might have been more reliable than trying to identify these types of critics from comments made in workshops as it could be that the most ‘hardened’ sceptic is the person who does not make any comment at all.

8.4 Review of research findings

In this section the research findings are summarised and discussed in relation to the research questions tackled.

8.4.1 Which innovation tools, if any, are potentially suitable for eco-innovation?

This question was answered through the review of existing innovation tools and the in-house trials, described in Chapter 5. The tool review identified ten tools which met the basic requirements of being tools that:

- can be applied during the very early stages of the innovation process (specifically, activities prior to the formulation of a formal requirements specification); and,
- encourage radical or ‘step-change’ innovation rather than incremental improvement.

The ten tools identified were: Future Scenarios, Backcasting, BEC Diagram, Ideal Final Result, Eco-value, Project Portfolio maps, Objectives Tree diagram, Functional Analysis, 9 Windows and Empathic Design. At this stage it was decided that the Empathic Design tools were not suitable for testing within this research due to the difficulties in organising workshops with real users within the limited time available within each company. The remaining nine tools were then adapted such that they could applied within an eco-innovation workshop. Over a series of workshops, the nine eco-innovation tools were tested by small groups of colleagues from within the Department of Mechanical Engineering. A variety of criteria were used to evaluate the tools and based on the results of this evaluation the following five tools were selected to be tested within the industrial trials: Future Scenarios, Eco-value, BEC Diagram, 9 Windows, Sustainable Final Result.

In reviewing the tool development activity it was noted that, although not pursued further within this research, there is potential to develop QFD for the Environment as a tool for eco-innovation as it can help with the important task of integrating environmental considerations into the product requirements specification and is already widely used within industry.

8.4.2 What are companies' initial responses to eco-innovation tools?

This research question was answered through the completion of a series of one-day workshops which introduced six companies to the five eco-innovation tools. A separate workshop was organised with each of the six companies. The workshops were attended by representatives from engineering, manufacturing, quality and EHS functions, although the engineering function was the best represented in all cases. The workshop involved an introduction, an activity and a feedback session for each of the eco-innovation tools.

As well as the specific findings about the companies' reactions to the tools, some of more general findings were:

- Staff from operational levels of the organisation including design engineers felt that strategic tools, such as Future Scenarios, would be applied by senior management and not by them.
- Companies tend to prefer eco-innovation tools that are easy to understand and apply. A strong visual component and step-by-step guidance appeared to characteristics that positively influenced the ease of use of a tool. It was suggested that companies may not elect to use tools that require any significant amount of effort to learn or apply.
- Design teams find it difficult to evaluate the design tools when they are not applying them to their own products.

The recommendations that follow from these findings are that:

- Developers of strategy-level eco-innovation tools must be aware of the way in which product and company strategy is managed within a particular company and ensure that they develop and test tools with the correct users.
- Eco-innovation tool developers should focus on generating tools that are easy to understand and apply, particular if they are aimed at companies that are new to eco-innovation.
- Developers of any type of design tool should wherever possible test tools with real design teams applying the tools to their own design tasks/problems.

8.4.3 Can innovation tools be customised to the eco-innovation requirements of a company? If so how?

These questions were answered through the two-week tool trials within four case-study companies in which one or two of the eco-innovation tools were selected by the company and introduced to the respective design teams. A design tool introduction process, based on previous work by Ritzén and Lindahl (2001) was used to structure this activity. The novel aspect of this process was that it uses tool customisation to increase the probability of a successful tool introduction. The stages of the tool introduction process are listed in Table 8.2, along with the research activities completed and the research findings.

Tool introduction process stage	Research activity	Outputs	Findings
1. Establish company need	Benchmarking activities	• Improved understanding of each company's environmental and innovation performance.	• Five key reasons why companies engage in eco-innovation identified: corporate brand protection and enhancement; product differentiation; improved innovation performance; legislative compliance (although this relates more to 'early eco-design' than eco-innovation); and cost reduction.
2. Evaluate potential tools	One-day workshop	• Specific insights into the performance and popularity of each of the five tools.	• Staff from operational levels of the organisation felt that strategic tools, such as Future Scenarios, would be applied by senior management and not by them. • Companies tend to prefer eco-innovation tools that are easy to understand and apply and may decide not to use tools that require any significant amount of effort to learn or apply. • Design teams find it difficult to evaluate design tools when they are not applying them to their own products.
3. Trial selected tool	Week 1 workshops	• See below.	• See below.
4. Establish design team need	Week 1 design team interviews	• Specific feedback about the performance of the one or two tools tested. • Specific feedback in order to precisely define the company's requirements for eco-innovation tools. • Tool requirement specification for each company.	• Development of tool requirement specification led to tool requirements that were more understandable and relevant for the design team and the company and could be used to drive the tool customisation activity.
5. Customise tool	Tool customisations	• Customised versions of tools developed for each company.	• Design team members are a useful source of tool customisation ideas.

Table 8.2: Summary of the research outputs and findings in relation to the tool introduction process (continued overleaf)

Tool introduction process stage	Research activity	Outputs	Findings
6. Retrial and re-evaluate tool	Week 2 workshops and design team interviews	• New product concept ideas generated • Specific feedback about the performance of the tools.	• In six out of eight instances, the tool customisations were considered to be successful based on the group feedback scores and comments from the individual feedback interviews. • Unsuccessful tool customisations attributed to the tool being too focused on strategic issues for the type of participant with which it was tested. • Successful tool customisations attributed to: using tool customisation ideas from the design team; facilitating the use of the tool for normal innovation activities as well as eco-innovation; and applying the tools to existing/real company projects. • Design teams favour tools that produce more detailed, tangible outcomes. • Because most of the design teams had no previous experience of eco-innovation, they were not entirely sure of their requirements of eco-innovation tools.
7. Roll-out tool across company	Drivers and barriers interviews	• Force-field analysis diagram produced for each case study. • Suggestions for the content of an eco-innovation strategy made. • Model of eco-innovation management defined.	• Previously identified reasons for engaging in eco-innovation confirmed as drivers for eco-innovation tool roll-out. • Main barriers to eco-innovation tool roll-out include: lack of senior management support; lack of separation between NPD activities and attempts at radical innovation; and the lack of an eco-innovation strategy.
8 Review periodically	Beyond scope of research	N/A	N/A

(Continued) Table 8.2: Summary of the research outputs and findings in relation to the tool introduction process

Based on the finding that the tool customisations were successful in six out of eight instances, the major conclusion was that *it is possible to customise tools to the eco-innovation requirements of companies*. Furthermore, this same finding confirms that one answer to the question of how tool customisation can be achieved is, ‘by following the tool introduction process described within this thesis.’ There may of course be alternative approaches but the process described has proven successful and is applicable to any type of workshop-based design tool. The application of this tool introduction strategy to more complex, software-based design tools is thought to be limited due to the difficulty and effort that would be required to customise third-party software.

The main strengths of the tool introduction process were concluded as being the ability to build an understanding of *why* a company wanted to engage in eco-innovation and *how* it needed tools to perform (e.g. requirements such as ease of use, ability for tool to be used by a multi-functional team etc.). However, further work is required on the process to help the practitioner determine *what* the company needs the eco-innovation tools for (e.g. highlighting market opportunities for eco-innovations vs. solving specific technical problems related to eco-innovation). It was suggested that this could be overcome by using a typology of innovation and creativity tools which could then be used to define the company need for eco-innovation tools more precisely. It was also suggested that the step of generating ideas for tool customisation based on the requirements would benefit from more formal analysis.

This research adopted an approach to encouraging the long term adoption of eco-innovation tools based on tool customisation and a systematic tool introduction process. Whilst this approach has led to successful tool customisations, it is not possible to say if this will lead to long-term tool adoption. It is also possible that some of the approaches not tested - such as improving the tool training programme or employing a more systematic approach to tool selection - may be more effective. Further research is required to compare different approaches to improving long term tool adoption.

Finally, it was noted that the research had been based on the assumption that design teams would be the main users of eco-innovation tools. In practice it was found that companies view eco-innovation as a predominantly strategic activity and that design teams generally have less involvement in such activities. It was suggested that companies need to ensure that operational-level staff play a more significant role in the application of strategy-focused eco-innovation tools if they want to access the latent knowledge and ideas their staff hold and thereby deliver more successful, eco-innovative products.

8.4.4 What are the drivers and barriers to the adoption of eco-innovation tools?

This question was answered primarily through the qualitative analysis of interviews held with members of the design team and senior management within each of the four case-study companies. This analysis was supplemented with evidence from the benchmarking activities and the tool trial workshops. In Chapter 7 a variety of drivers and barriers for the adoption of eco-innovation tools were highlighted. Force-field analysis diagrams were used to present these drivers and barriers under the themes of ‘people’, ‘process’, ‘context’ and ‘tools’. Cross-case analysis led to a number of findings:

- Legislation was found to be a driver of eco-design or early compliance activities but not for eco-innovation.
- If senior management support for eco-innovation is not clear and explicit the introduction of eco-innovation tools will be hindered.
- The demands of incremental NPD projects on staff time hinder a company’s ability to generate and execute radical innovation projects, including eco-innovation projects.
- The absence of a strategy for eco-innovation within a company is a barrier to eco-innovation.

In the following section the possible solutions proposed to these problems are presented.

8.4.5 Managing eco-innovation

None of the research questions specifically addressed the management of eco-innovation. However, a number of interesting findings concerning the management of eco-innovation emerged from the analysis of the interviews, benchmarking activities and the workshop feedback. These findings, which address a number of the issues raised in the analysis of the drivers and barriers for eco-innovation tools, were synthesised with the existing academic literature to produce a model of eco-innovation management, shown in Figure 8.2.

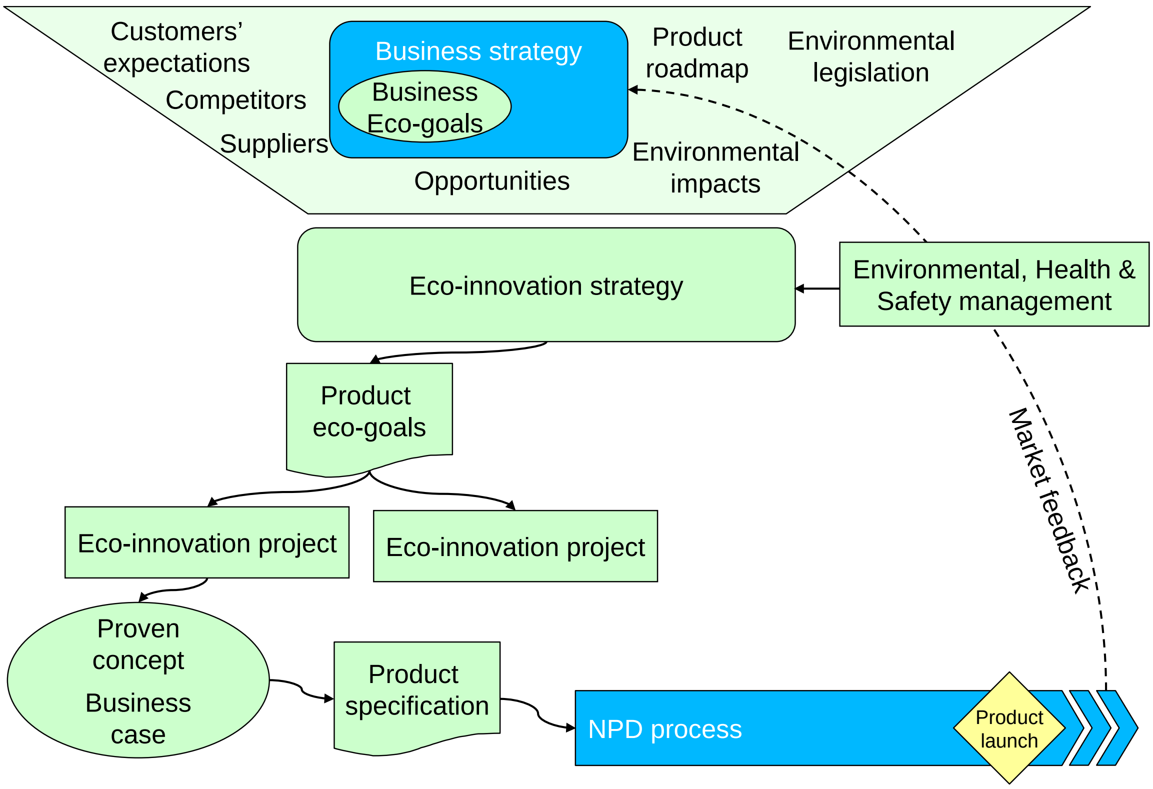

Figure 8.2: The revised model of eco-innovation management within a company

The main elements of the model are detailed below.

- *Eco-innovation strategy* - the lack of an eco-innovation strategy was highlighted as a significant barrier to the roll-out of eco-innovation tools within most of the case studies. This led to the recommendation that an eco-innovation strategy document should be produced, informed by things such as the company strategy, the main environmental impacts of the companies activities, customer expectations etc. It was suggested that the process of developing an eco-innovation strategy might be facilitated by applying the environmental strategies matrix proposed by Orsato (2006). This matrix defines four possible environmental strategies based on how a company achieves its competitive advantage, and the competitive focus it selects. Finally, it was recommended that an eco-innovation strategy document should include the following elements:
  - The rationale and business case for engaging in eco-innovation activities.
  - Guidance on how to select the environmental aspects of the company's activities to target.
  - Long-term targets for both operational environmental performance and eco-innovation performance of products ('product eco-goals').

- A description of how eco-innovation activities relate to the company's conventional NPD and innovation activities.

- *Separate eco-innovation projects* - to ensure that eco-innovation activities can be pursued away from the pressures and time constraints of NPD activities, it was recommended that they are completed in a dedicated form of 'pre-development' or 'research' project. By conducting one or two of these dedicated eco-innovation projects per year (rather than trying to incorporate eco-innovation into every project) the risk of staff being sidetracked by more urgent NPD projects should be reduced, the quality of the projects and the outcomes should be better, and any staff fears that eco-innovation is being pursued at the expense of 'normal innovation' should be allayed.
- *Proven concept, business case and product specification as project outcomes* – if eco-innovation projects can deliver a proof of concept prototype as a technical outcome then it should be feasible to incorporate the new technology or concept into a commercial product. This needs to be matched by a strong business case and a preliminary requirements specification for the product to be developed. With these three elements in place, a decision can be made by the management team whether or not to launch a full NPD project for the eco-innovation concept.
- *Project execution within a 'normal' NPD project* – with the major technical and commercial risks resolved, or at least sufficiently understood, the development of the eco-innovation can be executed within a 'normal' NPD project. This will allow the project to tap-in to the resources of the mainstream organisation whilst avoiding the need for, and cost of, separate management systems for eco-innovation.

This model was presented to the case study companies during the round-up seminar. It was agreed that this model represents a practical and logical approach to the management of eco-innovation. This model should provide a useful template for companies that wish to engage in eco-innovation, but as with any model, companies must take time to adapt this model to their own particular context and requirements.

Reflecting on the use of this model, in Section 7.3 it was noted that there are at least two 'entry points' for the model of eco-innovation management for companies:

- *Top-down* – whereby senior management initiate eco-innovation activities by first developing a set of business eco-goals which subsequently cascade down the impetus and requirement for eco-innovation projects.

- *Bottom-up* – whereby members of the design team initiate eco-innovation activities by utilising eco-innovation tools as part of existing NPD projects to identify some 'quick wins' and feeding back these success stories to senior management.

Another dimension of the model that could be explored is that of the maturity of the eco-innovation approach within a given company. The development and evolution of a company's approach to ECD over time is a theme that has previously been discussed in the academic literature (McAloone, 2000, Reyes et al., 2006) and would appear to be equally important in the case of eco-innovation. For instance, it could be that the final model of eco-innovation management presented in Figure 7.4 represents an ideal, mature approach to eco-innovation but that initially, companies might not have all of the features of the model in place. This is the case with the two model entry points described above in which, initially, there are eco-goals but no eco-innovation projects, or vice-versa. It would therefore be interesting to study companies that are different stages in the development of their approach to eco-innovation and to use the model to identify patterns in how these companies progress.

8.5 Contributions to knowledge

The aim of this research was to understand how eco-innovation tools can be developed and introduced to a company such that they are adopted into the long-term practices of the company and contribute to the development of eco-innovative products. By developing a range of eco-innovation tools and introducing these tools into four case-study companies, the contributions to knowledge of this research are:

- *The development of a toolbox for eco-innovation* – as there are currently relatively few tools that explicitly support eco-innovation activities, the development of more eco-innovation tools will help to ensure that companies looking for a tool to support a particular eco-innovation challenge will find a tool to meet their needs.

- *The validation of tool customisation as an approach to improving the introduction of eco-innovation tools* – tool customisation to the specific needs of a company has previously been suggested as a means of increasing the likelihood of ECD tool adoption. A number of attempts at applying some form of tool customisation strategy have been made previously, but these examples involved limited or no feedback on the effectiveness of this strategy and were based on experiences from single case studies. This research makes a contribution to knowledge by validating the tool customisation approach based on a formal review of the effectiveness of the tool customisations within four industrial case studies.

- *The definition of a generic process for tool introduction based on tool customisation which is appropriate for workshop-based design and innovation tools (including eco-innovation tools*) – building on the previous work of Ritzén and Lindahl (2001), the process for tool introduction defined incorporates tool customisation as a strategy for increasing the probability that new design and innovation tools will be adopted into the long-term practices of the company.
- *Insights into the organisational drivers and barriers for the long-term adoption of eco-innovation tools* – during the time spent embedded within the case-study companies, a significant amount of data was collected through workshops, interviews and observations that provided insights into the organisational drivers and barriers for the adoption of eco-innovation tools. This knowledge will be particularly useful to companies attempting to implement eco-innovation tools as they can use the insights to plan appropriate actions to reduce the barriers and enhance the drivers, with the aim of increasing the likelihood of tool adoption.
- *A model for the management of eco-innovation activities* – the model of eco-innovation presented is based on the data collected in industry about where the eco-innovation tools might be best placed in a process and other critical elements needed to manage eco-innovation (such as an eco-innovation strategy). The model addresses a number of the issues raised in the analysis of the drivers and barriers for eco-innovation tools. An important finding was that dedicated eco-innovation should be organised and sit ahead of a conventional NPD process that translates the outcomes of an eco-innovation project into market-ready products.

8.6 Recommendations for future research

This research has considered how eco-innovation tools can be introduced within a company in order to increase the likelihood that the tool will eventually be adopted within the working practices of the company. The evidence collected was used to verify the success of the tool introduction activities. However, it was not possible to confirm that a successful tool introduction will guarantee that a tool will be adopted in the long term. To empirically investigate this relationship, a longitudinal, multi-case study could be used, spanning from the introduction of a tool through to a point several years later. Such a study would provide a very useful contribution to knowledge, within both the specific area of eco-innovation and for engineering design research generally.

Other issues that were encountered during the course of this research and merit further academic study include:

- It was found that the design teams struggled with some of the eco-innovation tools due to their strategic-level focus. More research is required to understand who is involved in radical vs. incremental product innovation projects. This knowledge could be used by developers of eco-design and eco-innovation tools to ensure that they are addressing the requirements of the correct target audience.
- The definition of an eco-innovation strategy was a key recommendation within the model of eco-innovation management proposed. Further study is required to investigate the impact of putting in place such a strategy has on the adoption of eco-innovation tools and the effectiveness of eco-innovation activities more generally.
- QFD for the Environment (Masui et al., 2001) is a tool that can potentially help to generate detailed and accurate environmental requirements based on user needs. Further study is required to explore how this type of tool could be applied within an eco-innovation context in which product concepts are more radical and therefore more difficult for users to assess and provide feedback on.

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Appendicies

Appendix 1: Sample tool feedback interview transcript

Below is a sample interview transcript. The transcript is of an individual tool feedback interview from Week 1 of the tool introduction study at Aquaplus. For confidentiality reasons certain sections of the transcript have been omitted and replaced with a generic term in square brackets or '[confidential]'. The notation '[audio]' is used where the transcriber was unable to understand the conversation due to poor audio quality.

- JO - Jamie O'Hare
- RD – A Senior Design Engineer

JO: So, just a bit of background first of all. How long have you been with the company?

RD: About 10 years since I finished uni – was there four years as sponsored student as well.

JO: So, straight from University.

RD: Yes, 10 years.

JO: What is your job title?

RD: Senior Design Engineer.

JO: So, as I said, I am interested in your requirements of eco-innovation tools.

RD: Yes.

JO: The aim is to build up first of all a generic requirements specification for an eco-innovation tool so I can validate what we are doing and try and prove the tool for the second week of activities. I have described the design tool as a means that in a predefined and systematic way facilitates the users work towards a desired outcome – and some people might use the word 'method' as well, a design method, but I am just using the word tool. Examples of tools and methods would be things like brainstorming, CAD software, an Excel spreadsheet set up to do a stress calculation or FMEA. So, are you happy with what I mean by a design tool?

RD: Yes.

JO: So, what sort of tools do you currently use in your work?

RD: The tools we are use – I describe them as tools – we use CFD. Also we are using I-deas; some people are using NX. Obviously then we go through the process; basically we come up with designs then we prototype them in XP and [audio] shops producing parts for us and then we test them in the lab and evaluate them; obviously testing the performance and testing the life cycle test for bugs.

JO: Any other types of tools or anything that you use - Quality-Functional-Deployment - anything like that?

RD: We use FEA packages like ANSYS; we tend not to use them over here because we do quite a lot of brass bits but we can do MouldFlow on certain components, standard stuff.

JO: Of those tools is there anything about any one that you think makes it more useful to you? Is there anything about CFD, for example; do you consider that to be – the version you are using – do you consider that to be a good tool?

RD: I think with CFD basically we have gone and tried to use it over the years: we are trying to get into it in a lot more depth at the moment. I do not think we have got to the point where we are actually confident in using it in and it is showing us what we want to yet. I do not think that necessarily we are not going to get there, I think it is a learning curve for us at the moment. We have started to use it, so hopefully that should come good in the end.

JO: Moving on and thinking about the session we went through on Monday where we began by listing the requirements for the shower product and then placing it on that BEC diagram according to which of the stakeholders that requirement benefited. Then we looked at which of those requirements affected water usage and then tried to look at some of those in more detail and think about ways we could improve the water usage of the shower. I have got a list of generic requirements that people talked about that might be important for this type of eco-innovation tool. So, for each of them I will ask you how important you think that metric is and then I will ask how well you think this BEC diagram tool meets that metric.

RD: Yes.

JO: The first one is being time efficient – the time from start to finish should be short including the time for data collection or preparation. So, first of all, in general, how important is being time efficient for you when you have to use this type of tool?

RD: You are talking specifically about the tool really?

JO: How general is that criteria for you? That a tool is time efficient?

RD: Generally we need it to be fairly efficient; obviously we are working project wise; we are always looking at time scale; typically 9-12 months for delivery of project. In the last three or four years we have delivered a project every twelve months – a new product. So, anything that we can include needs to be done in that sort of time scale. Obviously in that 9-12 months you have got a period of tooling anyway so a lot of the design is done in two or three months, obviously with development as you go through.

JO: So the conceptual design is that done in a fairly short period – is that the 2-3 months you are talking about?

RD: It can do; it depends on how simple or how complex your conception [audio] but yes, we are a couple of months from a fact sheet to actually getting to a solution.

JO: In general first of all then, if we had to rate this criteria as being not important through to critical, one to five, where would you score this criteria of time efficiency?

RD: Probably 4; obviously the quality of the product has got to be right. So that is probably the top priority, but obviously delivery of timescales is probably the next thing.

JO: Then thinking about this BEC diagram tool, how time efficient would you rate that as being? So, 1 the tool does not meet this requirement or 5, it meets it satisfactorily.

RD: It is a fairly quick thing to do; obviously it depends on the quality of things coming out of it.

JO: Yes.

RD: It is pretty quick; I would say it is a 4-5, somewhere between that. Obviously we have not used it in a proper project so I can see it working.

JO: You say it depends on the quality of the outputs?

RD: Yes.

JO: What did you mean by that?

RD: I think one of the difficulties with the tool is that, on showers especially, in terms of the tool producing the amount of volume of water we use – I mean if you compare a shower to a bath it is already economic in terms of the amount of water and from a commercial design point of view it is down to the customer. If the customer wants to save water they have a two minute shower. If they do not want to save water they have a ten minute shower and there is not much we can do about that really. So, in terms of water savings that [flow rate] in their, but again it is down to the customer – is that what they want? Obviously, people like to have more water.

JO: Are you thinking about the value of the outputs?

RD: Yes, if you came up to me to say that you could … all the showers could be recycled so we could get everything back and use all the product again or use all the materials again, then that would be a very good sort of thing to come out of it, but there is obviously a lot of these showers … we get electric showers in there; they've found them and we send them off to landfill. Obviously that depends on the materials; obviously brass we recycle, but the plastics are more difficult.

JO: The next metric is – the tool is easy to learn, use and understand? How important do you think that is general for an eco-innovation tool?

RD: Yes, I think it has got to be relatively intuitive. You do not want to be spending more time working out how to use it than actually using it, but I think it is fairly simple – everyone has seen diagrams and it is good to split it out and look at ones and which areas they fall into.

JO: Do you have a score to how important the metric is, one to five?

RD: How easy it is to learn or how important it is…?

JO: How important it is that a tool in general is easy to learn, use and understand?

RD: Either 4 or 5; I do not think it necessarily needs to be critical, it is actually … I think I'd say 4 because if it is slightly difficult to learn but you can still learn it and get good use out of it, it is worthwhile for the effort, then it is worth the effort; if that makes sense? Things like I-deas that we use are not particularly easy to learn; there are lots of little things that are weird and wonderful about it, but obviously we would not be able to do what we do without it so…

JO: Then thinking about this tool, how well did it meet that requirement to be easy to learn, use and understand?

RD: Yes, I think probably 5; I think the thing meets it.

JO: The next one is 'early phases'; so, the tool must be applicable during the early stages of the new product development process. So, first of all, in general, how important do you think that metric is?

RD: To a certain extent it ties on the project and what we are trying to achieve with the project. If we are looking at an eco-project and that is one of the key drivers, then obviously that is going to be very important to have it in right at the start. If you are looking at something that is cost driven, where they want cheap parts and good margins then it might not necessarily fall into that category, if that makes sense?

JO: Yes. So other projects, make them more cost driven and hence this … there would be less…

RD: Things like the [confidential] an example where the margin is not piled on that as it is on other products so obviously we are looking at Far East supply and factoring it in, so virtually the control on what goes on on their processes is not the same as something that is built here, but…

JO: So, to give a score to that, in general, how important is that metric?

RD: I think probably 3 – somewhere between, depending on the project.

JO: How well do you think this tool could be used during the early phases?

RD: I think it could be used quite well and quite easily if that was what we wanted to do; that would be 5 on that.

JO: The next one is 'low quality data'; during the early stages of product development often only qualitative or ballpark numbers are available and hence the tool must be able to deal with these types of data. How important is that in general for this type of tool?

RD: When you say low quality data do you mean…?

JO: Not as precise and more uncertainty.

RD: Things like number of [audio] product we are going to sell and that sort of thing?

JO: Yes; earlier in the project that data is less certain and less precise and later in the project normally it is more precise – costings and things like that. How important is it that this type of tool can deal with that type of data?

RD: Obviously it needs to – if you are doing [audio] of this the impact on costs then you need to factor that in, so that is reasonably important. If there is any effect on timescales, whether you take on when it is developed [audio] and it comes out of this then, again, that needs to be put in there. I would not have thought … meanwhile if you use this in production, I would not have thought there would have been too much that would affect … obviously the cost might do, but the timescales I would not expect to be affected too much.

JO: So to give it a score then – one to five, how important the ability to use the low quality data is?

RD: I would probably say a 3.

JO: Thinking specifically about this tool – how well do you think it meets that requirement?

RD: I think it does in terms of … obviously there is not a great deal of data to actually get into it – a lot of it is more general anyway so I would probably say a 4.

JO: The next one is 'lifecycle perspective'; the method should consider all phases of the product lifecycle and the environmental impact associated with those –

so materials extraction, production, distribution use and disposable. How important is that in general for this type of tool?

RD: For this tool or for the tools generally?

JO: For eco-innovation tools in general. If you wanted a tool to help you look at entire lifecycle of the product?

RD: I think from an eco point of view that is really the key thing really; looking at it from the start to the finish really. Materials are trash and we don't really go into it, we just buy the material, but if you wanted to claim [unclear] as a true eco-product then that is what you would have to look at. Whether it was recycled brass or … look at the whole route. Obviously production methods, you have got how much CO_2 or whatever you can do – put a measure on that, can't you? So, that is that important; you can see loads of cars all the time, but its only about emissions and CO_2 emissions…

JO: Per kilometre…

RD: Obviously tax you on it as well; distribution is another one because obviously, as a company we bring bits in from China – that is something that we really need to look at; whether it is viable or not viable. I know the reasons why we do it. Use is probably down to the flow rate really and whether you can recycle water and the disposal list – what you do with the product; whether you strip all the brass out of it. From a mixer point of view, obviously the electrics are plastic; I would say that is probably the most import part of eco.

JO: So to give it a score?

RD: Probably a 5 on that one, yes.

JO: How well do you think this tool covers the lifecycle of the product?

RD: I think it does it well; you are obviously looking at the customer and manufacturing side of it, so it picks up on all that kind of thing so I would say a 5.

JO: Marketing aspects; the tool must encourage the consideration of marketing aspects. How important is that in general for an eco-innovation tool?

RD: I think it is relatively important, especially if you are going to make a big play on the eco side of it for the marketing side of it; it does do quite a lot because you are considering the customer and obviously the marketing side of it deals with what the customer wants. Obviously there is an education part of it as well, making people aware of how to have an economic shower – an eco-shower; but it depends on the product – the placement of it, so I would not say it is critical. So we can put a 3 on that one. I think it does do it [unclear] considering the customer, therefore I'd suggest you can get across to them and obviously they have to take that and market it and get it across to them. But, in terms of making people aware of it, it does that quite well.

JO: The final one here is 'a multi-functional team'; the tool must support working in a multi-functional team [unclear] practically exchange of information between different organisational units. Can you work on this with manufacturing, marketing people? How well could this tool be used by all of those together in one session?

RD: Well, we had a marketing guy; we had manufacturing guys and guys from the lab and we have a fairly sort of multi-functional team. We have [unclear] side of it, we have got engineers, we've got manufacturing; we have got purchasing, marketing come over and sit with us. We have got a wide team; we also get involved with … we've had [a retailer] and [another retailer] come in. [A retailer] came in last week; [another retailer] in next week; we're more dealing as a unit, as a team. We have things like … I cannot remember the exact name, but basically they are business units and then you have orders from relevant people – so you have the guy from marketing and [a manager] is my boss for the day, and then you have sales guys and various other people get involved; and just sit down and look at what actual products they want from the start; I think we are fairly good at getting that sort of team together.

JO: So, how important is it that this type of eco-innovation tool can support that type of…?

RD: I think it is fairly important; I think I would go for a 4 on that one. I would not say it was critical because each team could use it independently almost, so you can have someone in marketing actually going away and focus exactly how they would market it; use it to come up with those sorts of benefits. Whereas we could go away and look at all the … you might have to just look at almost a manufacturing side of it. [Unclear] together and do everyone together.

JO: So, just to give a score to how well this tool meets this requirement.

RD: I think it does it fairly well, obviously you have got to try it to see it in action, but I think it will be a 5 again.

JO: We have gone through these requirements here - time of use and ease to learn, use and understand, early phases, low cost data, lifecycle perspective, marketing perspectives and multi-functional team. Are there any other important requirements that you would have for the tool that cannot go in under those headings?

RD: Not that I can think of at the moment.

JO: Is there anything about the tool that you would like to change?

RD: Not that I can think of really; I think maybe looking at actually getting people to think of different ways of being eco, because I think there is a lot of the times things … I mean, obviously minimising water use; just getting people to think about it from different angles because it is quite interesting to watch various people. The guy who processes data at the test lab was saying that we should reduce the amount of testing we do to reduce the amount of water – so it is getting people to think about just what their area is; the whole thing.

JO: So, encourage people to think outside of their own domain, or…?

RD: Just thinking about it almost like … if you want a shower [unclear] the whole working through the process. It is difficult to explain really; I do not know if there is anything really different, radically different that you could actually do but…

JO: Finally, basically any other comments about either your requirements for this type of tool or how the tool performed?

RD: I think the key for it is the next phase where you take these bits from there and actually how you would educate … I mean, things like how you would educate the customer to get away and thinking … we could probably think about an actual display of the cost of a shower – what is the best way of doing that? And what is the best way people would understand? I mean, once you are putting a value on it of £s is fairly understandable, but whether you incorporate that into literature or whether you just put that into an actual physical component on the shower.

JO: So, you would like to think that in the tool or the process of applying the tool that would encourage you to get more detail into these ideas.

RD: Yes.

JO: Okay.

Appendix 2: Final coding scheme

The coding scheme developed by the researcher for the purpose of this research is presented in the table below. The code structure is hierarchical, with the high-level themes in the first column and cascading levels of themes in the subsequent columns.

Introduction			
Introduction	Customisation to requirements		
Introduction	Customisation to requirements	Business requirements	
Introduction	Customisation to requirements	Business requirements	Ability to deliver wider business benefits
Introduction	Customisation to requirements	Business requirements	Multi-purpose
Introduction	Customisation to requirements	Designers' requirements	
Introduction	Customisation to requirements	Designers' requirements	Accuracy
Introduction	Customisation to requirements	Designers' requirements	Language
Introduction	Customisation to requirements	Designers' requirements	Evaluating ideas
Introduction	Customisation to requirements	Designers' requirements	Use of low quality data
Introduction	Customisation to requirements	Designers' requirements	Marketing aspects
Introduction	Customisation to requirements	Designers' requirements	Use in early phases
Introduction	Customisation to requirements	Designers' requirements	Lifecycle perspective
Introduction	Customisation to requirements	Designers' requirements	Use with different people
Introduction	Customisation to requirements	Designers' requirements	Time requirement
Introduction	Customisation to requirements	Designers' requirements	Quality of outputs
Introduction	Customisation to requirements	Designers' requirements	Ease of learning and use
Introduction	Tool value		
Introduction	Tool value	Benefit to company	
Introduction	Tool value	Benefit to designer	
Introduction	Unmet tool requirement		
Roll-out			
Roll-out	Project		
Roll-out	Project	Project impact	
Roll-out	Drivers for implementation		
Roll-out	Drivers for implementation	Desire to improve environmental performance	
Roll-out	Drivers for implementation	Desire to improve environmental performance	Other functions
Roll-out	Drivers for implementation	Desire to improve environmental performance	Corporate
Roll-out	Drivers for implementation	Desire to improve environmental performance	Designers
Roll-out	Drivers for implementation	Demand for use (of tools)	
Roll-out	Tool success		
Roll-out	Tool success	Concept ideas	

Roll-out	Tool success	Engagement	
Roll-out	Tool success	Ideas for tool improvements	
Roll-out	Tool failure		
Roll-out	Roll-out process		
Roll-out	Barriers to implementation		
Company			
Company	Management support		
Company	Management support	For design	
Company	Management support	For tool use	
Company	Management support	For environmental issues	
Company	Culture		
Maintenance			
Innovation			
Innovation	Tools		
Innovation	Tools	Support (not management)	
Innovation	Tools	Use of non-eco tools	
Innovation	Project selection		
Innovation	NPD		
Innovation	NPD	User requirements	
Innovation	NPD	User requirements	Designer-User interaction
Innovation	NPD	User requirements	Knowledge in general
Innovation	NPD	User requirements	Management
Innovation	NPD	Process	
Innovation	Organisation		
Innovation	Organisation	Pre-development activities	
Innovation	Radical		
Innovation	Performance		
Innovation	Product strategy		
Innovation	Product strategy	Control	
DFE			
DFE	Eco-innovation		
DFE	Eco-innovation	Impact of eco-innovation	
DFE	Eco-innovation	Impact of eco-innovation	On innovation activities
DFE	Eco-innovation	Impact of eco-innovation	On product sales
DFE	Eco-innovation	Ownership of eco-innovation	
DFE	Eco-design		
DFE	Existing eco-projects		
DFE	Strategic alignment and integration		
DFE	Strategic alignment and integration	Integration with NPD	
DFE	Product environmental targets-requirements		
DFE	Authenticity		
DFE	Agency		
DFE	Understanding of lifecycle		

	impacts		
Environmental			
Environmental	Perceived seriousness of impacts		
Environmental	Performance		
Environmental	Operational environmental impacts		
Environmental	Champion		
Environmental	Environmental mission statement		
Context			
Context	Economic		
Context	Supply chain		
Context	Competition		
Selection			
Motivation			
Motivation	Market demand for eco-innovations		
Motivation	Environmental legislation		
Bias			
Facilitation			
Chat-Introduction			